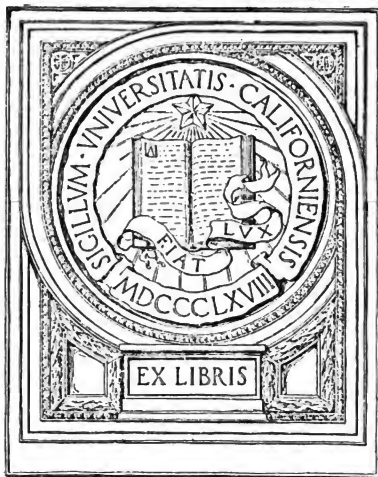


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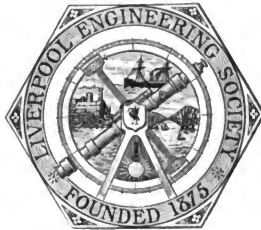


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TRANSACTIONS
OF THE
LIVERPOOL ENGINEERING SOCIETY.

VOL. XLII.

FORTY-SEVENTH SESSION.



EDITED BY

Assoc. Professor T. R. WILTON, M.A. (*Cantab.*),
M. Inst. C.E., M. Cons. E.

LIVERPOOL:

PUBLISHED BY THE SOCIETY,
ROYAL INSTITUTION, COLQUITT STREET.

1921.

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(1)	{ 1875-76 }	<i>C. Henry Graham Smith,</i> Assoc. M. Inst. C.E. }	(Died 9th September, 1884)
(2)	1878	ROBINSON SOUTTAR, M.A., B.C.L. (<i>Oxon.</i>)	
(3)	1879	M. E. YEATMAN, M.A. (<i>Univ. Camb.</i>), M. Am. Soc. C.E.	
(4)	1880	ALEXANDER ROSS, M. Inst. C.E.	
(5)	1881	<i>Alfred Holt, M. Inst. C.E.</i>	(Died 28th November, 1911)
(6)	1882	FRANK B. SALMON, M.I. and S. Inst.	
(7)	1883	<i>Henry Bramall, M. Inst. C.E.</i>	(Died 10th July, 1909)
(8)	1884	R. RATSEY BEVIS, Junr., M. Inst. C.E.	
(9)	1885	WILLIAM E. MILLS, F.S.I.	
(10)	1886	COARD S. PAIN, Assoc. Inst. C.E., F.S.I.	
(11)	1887	<i>John J. Webster, M. Inst. C.E.</i>	(Died 30th October, 1914)
(12)	1888	CHAS. H. DARBISHIRE, J.P., Assoc. M. Inst. C.E.	
(13)	1889-90	{ <i>Henry H. West, M. Inst. C.E., M. Inst. N.A.,</i> <i>M.I. Mech. E.</i> }	(Died 13th August, 1906)
(14)	1890-91	FERDINAND HUDLESTON, M. Inst. C.E.	
(15)	1891-92	JOHN T. WOOD, M. Inst. C.E.	
(16)	1892-93	<i>Robert E. Johnston, M. Inst. C.E.</i>	(Died 28th September, 1913)
(17)	1893-94	H. PERCY BOULNOIS, M. Inst. C.E., F.S.I.	
(18)	1894-95	H. S. HELE-SHAW, D. Sc., LL.D., Wh. Sc., F.R.S., M. Inst. C.E., M. I. Mech. E., F.R. Met. Soc.	
(19)	1895-96	ARTHUR J. MAGINNIS, M. Inst. C. E., M. I. Mar. E.	
(20)	1896-97	S. B. COTTRELL, M. Inst. C.E., M.I. Mech. E.	
(21)	1897-98	<i>George Farrer, J.P., M. Inst. C.E., F.R.S.S.</i>	(Died 10th April, 1901)
(22)	1898-99	JOHN A. BRODIE, M. Eng. (<i>L'pool</i>), Wh.Sc., M. Inst. C.E., M.I. Mech. E.	
(23)	1899-00	A. BROMLEY HOLMES, M. Eng. (<i>L'pool</i>), M. Inst. C.E., M.I.E.E.	
(24)	1900-01	Sir JOHN A. F. ASPINALL, M. Eng. (<i>L'pool</i>), M. Inst. C.E., M.I. Mech. E., M.I. and S. Inst.	
(25)	1901-02	ARTHUR MUSKER, M. Inst. C.E., M.I. Mech. E.	
(26)	1902-03	ERNEST S. WILCOX, M. Inst. C.E.	

- (27) 1903-04 THOMAS L. MILLER, O.B.E., M. Inst. C.E., M.I. Mech. E., M.I.E.E.
- (28) 1904-05 *Frank E. Priest, M. Inst. C.E.* (Died 14th April, 1920)
- (29) 1905-06 J. RESEY SMITH, M.I. Mech. E., M. Inst. N.A.
- (30) 1906-07 A. F. FOWLER, M. Inst. C.E., M.I. Mech. E.
- (31) 1907-08 *Thomas Duncanson, M. Inst. C.E.* (Died 2nd April, 1913)
- (32) 1908-09 A. R. T. WOODS, M.I. Mech. E., M. Inst. N.A.
- (33) 1909-10 WILLIAM BRODIE, M. Inst. C.E.
- (34) 1910-11 *Edvard Allen, M. Inst. C.E., M. Inst. Gas E.* (Died 15th July, 1915)
- (35) 1911-12 W. J. WILLETT BRUCE, O.B.E., M. Inst. N.A., M.I. Mar. E.
- (36) 1912-13 W. H. WATKINSON, M. Eng. (*L'pool*),
M. Inst. C.E., M.I. Mech. E., M.I.E.E.
- (37) 1913-14 FRANCIS E. COOPER, Assoc. M. Inst. C.E.
- (38) 1914-15 ERNEST C. GIVEN, M. Inst. C.E., M.I. Mech. E., M. Inst. N.A.
- (39) 1915-16 E. W. MARCHANT, D. Sc. (*Lond.*), M.I.E.E.
- (40) 1916-17 THOMAS M. NEWELL, M. Inst. C.E.
- (41) 1917-18 HAROLD DICKINSON, M. Inst. C.E., M.I. Mech. E., M.I.E.E.
- (42) 1918-19 J. WEMYSS ANDERSON, M. Eng. (*L'pool*), M. Inst. C.E., M.I. Mech. E.
- (43) 1919-20 J. HAMILTON GIBSON, O.B.E., M. Eng. (*L'pool*),
M. Inst. C.E., M. Inst. N.A.
- (44) 1920-21 J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.

The names of those deceased are printed in italics.

LIVERPOOL ENGINEERING SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

XLVII SESSION.—1920-1921.

COUNCIL.

In accordance with Rule V, the following Council commenced its duties on the first Wednesday in November, 1920, and will continue in Office until the first Wednesday in November, 1921.

President.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.

Vice-Presidents.

JAMES B. WILKIE, M.I. Mech. E., M. Inst. N.A.

Professor T. B. ABELL, O.B.E., M. Eng. (*L'pool*), R.C.N.C. Ret., M. Inst. N.A.

Members of Council.

J. E. LLOYD BARNES, Wh. Sc.,
M.I. Mech. E.

WILLIAM BRODIE, M. Inst. C.E.

W. J. WILLETT BRUCE, O.B.E.,
M. Inst. N.A., M.I. Mar. E.

JOHN DYKES, M. Inst. N.A., M.I. Mar. E.

RALPH E. GIBSON, M. Inst. C.E.

*THOS. L. MILLER, O.B.E., M. Inst. C.E.,
M.I. Mech. E., M.I.E.E.

C. A. NEEDHAM, A.M.I. Mech. E.

HERBERT NEVILLE, M.I. Mar. E.,
A.M.I. Mech. E.

B. G. OXFORD, Wh. Sc., M. Inst. N.A.,
M.I. Mar. E.

A. T. WALL, O.B.E.,
A.R.C. Sc., M. Inst. N.A.

Eng.-Capt. J. T. H. WARD,
M.V.O., R.N. Ret.

Professor W. H. WATKINSON,
M. Eng. (*L'pool*), M. Inst. C.E.,
M.I. Mech. E., M.I.E.E.,

Past-Presidents.

In accordance with Rule IV, the following Past-Presidents are ex-officio Members of Council for five consecutive years after their retirement from Office.

Professor E. W. MARCHANT, D. Sc. (*Lond.*), M.I.E.E., 1915-1916.

THOMAS M. NEWELL, M. Inst. C.E., 1916-1917.

HAROLD DICKINSON, M. Inst. C.E., M.I. Mech. E., M.I.E.E., 1917-1918.

Professor J. WEMYSS ANDERSON, M. Eng. (*L'pool*),
M. Inst. C.E., M.I. Mech. E., 1918-1919.

J. HAMILTON GIBSON, O.B.E., M. Eng. (*L'pool*),
M. Inst. C.E., M. Inst. N.A. 1919-1920.

Honorary Solicitor.—ERNEST W. PIERCE,

Deputy Town Clerk, Municipal Buildings, Liverpool.

Honorary Librarian.—BERNARD RATHMELL, M.I. Mech. E.,

11, Redcross Street, Liverpool.

Honorary Treasurer.

Professor E. W. MARCHANT, D. Sc. (*Lond.*), M.I.E.E.,
Liverpool University.

Honorary Secretary.

Assoc. Professor T. R. WILTON, M.A. (*Cantab.*), M. Inst. C.E., M. Cons. E.,
Westminster Chambers, 1, Crosshall Street, Liverpool.

* Resigned on 3rd November, 1920, Mr. W. E. Mills being appointed to fill the vacancy.

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TO THE
ASSOCIATION



J. R. DAVIDSON, C.M.G., M.Sc. (VICT.), M. INST. C.E.

PRESIDENT OF THE LIVERPOOL ENGINEERING SOCIETY.

XLVII SESSION — 1920-21.

LIVERPOOL ENGINEERING SOCIETY.

FORTY-SEVENTH SESSION.

First Meeting—3rd November, 1920.

J. HAMILTON GIBSON, O.B.E.,
M. Eng. (*L'pool*), M. Inst. C.E., M. Inst. N.A.,

The Retiring President.

INTRODUCED TO THE MEETING

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,

The President-Elect,

WHO THEREUPON TOOK THE CHAIR AND DELIVERED THE FOLLOWING

INAUGURAL ADDRESS.

GENTLEMEN,

Before proceeding with my Address, I wish to express my deep appreciation of the great honour you have conferred upon me in electing me to the Presidential Chair.

I realize to the full the great and honourable traditions which my predecessors in office have established and handed down, and with your support and confidence I will endeavour, to the best of my ability, worthily to maintain the dignity of my position.

The choice of a subject for a Presidential Address is probably, in most cases, as difficult a matter as the preparation of the Address itself. Faced with this task, I naturally turned to the roll of Past Presidents of our Society, and was at once struck by the scarcity of hydraulic engineers amongst the many distinguished names in the list. So far as I am aware, the only one who was engaged throughout his professional life in waterworks practice was our dear friend and my respected colleague, Thomas Duncanson.

A glance through the names of Past Presidents of our Parent Institution, discloses abundant evidence of the honourable part borne by hydraulic engineers in the Councils of that body. James Simpson, Thomas Hawksley, John Frederic Bateman, Sir Robert Rawlinson,

James Mansergh and Charles Hawksley, were all eminent engineers in the widest sense of the word, and their work worthily represents the modern development of hydraulic engineering.

My task, so far as the selection of a subject is concerned, is therefore the more easy, and I make no apology for addressing you to-night on that branch of engineering with which I have been more particularly associated.

ANCIENT WORKS.

No Presidential Address would be complete without some reference to early practice in the particular field of engineering under review, and as the hydraulic engineer may justly claim that his craft goes back to prehistoric days, I do not require to impose that strain upon your imaginations which has been necessary in the case of some of my predecessors in their endeavour to impart a flavour of antiquity to their subject. India, Ceylon, Mesopotamia and Egypt furnished a great field for the work of the hydraulic engineer in very remote days. In these and other Eastern countries of early civilization are still to be found the remains of works, which show that the construction of reservoirs and canals for irrigation purposes was carried out on a magnificent scale in almost prehistoric times. Earthen dams of a magnitude not excelled by the works of to-day were successfully constructed for the impounding of water, and many theories have been advanced as to the methods adopted by the ancient engineers, responsible for these schemes for the regulation and control of the flow of water from their reservoirs.

At a later period in the development of engineering achievement, works on the grandest scale were constructed for the supply of the great cities of the ancients. Water was brought to Carthage across 60 miles of desert by a magnificent aqueduct, portions of which still remain, carried on masonry piers with a double tier of arches 125 ft. in height. In Greece, Athens and Corinth were served with monumental works in keeping with the magnitude of those cities, while Jerusalem occupied a noteworthy position amongst these ancient cities on account of its fine water undertaking. A tunnel nearly 600 yards in length, forming part of an aqueduct for the supply of Jerusalem, still bears evidence to the engineering skill of King Hezekiah. There is every reason to believe that the remainder of the scheme was equally successful, for we read that "Hezekiah prospered in all his works."

During the Roman occupation of Palestine other important waterworks were carried out, and it is interesting to learn that when the victorious British Forces, under General Allenby, occupied

Jerusalem, the troops were supplied by water brought in from Wady-el-Arub, 16 miles south of the city, a source of supply which is believed to have been originally developed by Pontius Pilate.

Portions of an ancient aqueduct discovered near Patara, prove that the hydraulic engineers of those early days were not tied to aqueducts in which the water flowed throughout its length with a free water surface, for in this case a considerable ravine was crossed by an inverted syphon pipe. This pipe was formed out of stone blocks about 3 feet cube, each block having a hole 13 inches in diameter bored through the centre and an annular projection formed on one end which fitted into a recess 3 inches deep in the next block. The joints were made watertight with cement, and the blocks were held together by metal bands leaded into the stone.

The first detailed account of important works for the supply of a city, which has come down to modern times, is the valuable description of the water supply of ancient Rome, written by Frontinus. Sextus Julius Frontinus was trained as a surveyor, and afterwards had a distinguished military career abroad, taking a prominent part in operations against the turbulent tribes in South Wales. Returning to his native city, he was appointed *Curator Aquarum* about the year A.D. 97, and continued in that important office during the reigns of the Emperors Nerva and Trajan.

Frontinus evidently took a serious view of his duties, for he proceeded to write an essay, entitled :—*De Aquis Urbis Romæ*, in which he starts by enunciating the excellent principle that “I therefore “consider it to be the first and most important thing to be done . . . “to learn thoroughly what it is that I have undertaken.” This work has been made available for English readers through the enthusiasm of Mr. Clemens Herschel, an American engineer, who has published a copy and translation of the original codex of Frontinus, *De Aquis*, written and still preserved in the Monastery of Montecassino in Italy.

Frontinus not only gives particulars of the nine great aqueducts by means of which water was brought into the city, but goes into considerable detail regarding the distribution and measurement of the water and the regulations under which it was supplied.

It is interesting to note that the Anio Vetus, which was the second of the aqueducts, was constructed out of “the sum realised by the sale “of the spoils taken from Pyrrhus.” This is a decided improvement on the modern practice of waging war, when apparently the vanquished pays very little in hard cash, and the victor is reduced to the verge of bankruptcy.

The aqueducts known as Appia, Marcia, Julia, Augusta and Claudia, were so named after the engineers who carried out the work, following the pleasing custom of the old Romans in naming their roads and other great undertakings after the engineers responsible for their construction.

After describing the aqueducts, the worthy Frontinus pardonably exclaims :—"Will anybody compare the idle Pyramids or those other "useless though much renowned works of the Greeks with these aqueducts, with these many indispensable structures?"

The modern water engineer is familiar with the deplorable effect upon the pressure in his distribution mains, resulting from the action of citizens who water their gardens on summer evenings, but few are aware of the antiquity of this reprehensible practice.

Hear what Frontinus has to say on this subject, and the action of other malefactors.

"The cause of this is the fraud of the water men, whom we have "detected diverting water from the public conduits for private use, but "a large number of proprietors of land also, whose fields border on the "aqueducts, tap the conduits; whence it comes that the public water "courses are brought to a standstill by private citizens, yea, for the "watering of their gardens. And would that we were not having daily "experience by actual infringement of the law that all these mis-demeanours are committed just as flagrantly now as then. Irrigated "fields, shops, garrets, even; lastly, disorderly houses, have we found, "fitted up with constantly flowing fixtures."

It is evident that the duties of the waste water inspector were sufficiently arduous in those times, and when we read to-day of the discovery in certain American cities of unauthorised 12-inch connections illegally supplying private companies from the public mains with nearly one million gallons per day, it is doubtful whether the morals of some water consumers have improved to the extent which might be expected in nineteen centuries.

The Roman engineers followed closely the victorious march of their armies to the West, and many traces of their great waterworks still exist in France, Spain, and to some extent in England.

MODERN DEVELOPMENTS.

After this brief survey of the water supply of the great cities of ancient history, I now turn to the work of the hydraulic engineer in more modern times.

It is easy to see what an important part the question of water supply bore in the selection of the site of our old cities in this country.

Gradually, as the community increased in size, the yield of springs was augmented by the sinking of wells, and as the times became more settled, it was possible to bring water in from outside the fortified boundary of the town. A number of English towns obtained powers to construct waterworks in comparatively early times, though in many cases these powers were not exercised and were allowed to lapse.

Southampton had its municipal supply in 1420, and was followed by Hull in 1447, Bath in 1500, Plymouth in 1590, and Rye and Oxford in the 17th century.

The first private Act of Parliament relating to London water was obtained in 1543, but, beyond the installation of pumps driven by water wheels fixed in the arches of London Bridge, very little was done to supplement the supplies from springs and streams in the immediate neighbourhood until the celebrated New River Works were constructed by Sir Hugh Middleton, in 1613. By this scheme water was brought from the Amwell, Chadwell and other springs in Hertfordshire to reservoirs at Clerkenwell, where, very appropriately, the new offices of the Metropolitan Water Board have just been built on the site still known as New River Head.

When piped supplies were first introduced the distributing mains were made of wood, usually elm, the solid sections of the tree trunk being bored through and jointed by a tapered end driven into a corresponding socket on the next pipe. The limiting size possible for this form of pipe was 7 in. or 8 in., and the useful life did not exceed 20 years. Many of these pipes have been found in Liverpool, and also valves wholly constructed in wood for regulating the flow of water. The communication pipes were, as at present, made of lead. Cast iron replaced wooden pipes in London, in 1820, and to this day this form of pipe is most generally used.

The application of steam power to pumping machinery, by James Watt, in the latter half of the 18th century, gave a great impetus to the promotion of water supply schemes, and in many undertakings where the supply is derived from underground sources, beam engines are still to be found at work, which are direct links with the earliest type of pumping engine.

The next great step in connection with water supply took place in 1829, when James Simpson, the engineer to the Chelsea Water Company, introduced filtration by passing water vertically through a bed of sand. By this process, Simpson was undoubtedly endeavouring to produce a water as clear as that obtained from deep wells, where the water is naturally filtered by passing through the permeable strata, and for a

considerable number of years the efficiency of filtration was measured by the amount of turbidity removed from the water.

At that time it was not recognised that slow sand filtration had anything more than a coarse mechanical straining effect, and even the introduction of the chemical examination of water did little to change this opinion, as filtration has very little effect upon the chemical composition of the water. It was not realised until the comparatively recent discovery of the presence of bacteria in water and their relation to health that the sand filter was an infinitely more delicate and efficient instrument than had been imagined. It then became apparent that nearly the whole of the purification is effected by the film of sediment which is deposited upon the surface of the sand, and that this film in itself constitutes a filter so fine as to intercept the bacteria which may be in the water. The micro-organisms retained by the film form a gelatinous coating which plays a very important part in the process of purification.

Various detailed improvements in the design of slow sand filters have been made, and I believe there is still something to be learnt of the effect of aeration upon the water before passing through the bed, but the principle remains the same to-day as when James Simpson laid down his first filter nearly 100 years ago.

An important advance in connection with the supply to towns was made in 1830, when Thomas Hawksley, at the age of 23 years, introduced the constant supply system at Nottingham. From a health point of view this was a great step, as under the old intermittent system an originally wholesome water was frequently so polluted during storage as to be a great danger to the public health. Contrary to what might be expected, the constant supply system also resulted in the reduction of waste, as it at once became necessary to devote increased attention to the provision of proper fittings and connections.

Returning to the question of filtration, reference must be made to the considerable use which has been made in more recent years of mechanical filtration. Mechanical filters were first introduced in connection with trade supplies where a water free from all suspended matter was essential, but they are now being installed on an increasing scale in connection with water supply undertakings, and under certain conditions have considerable advantages. In this system, the water is forced through sand contained in a closed vessel under considerable pressure, the sediment film on the slow sand filter being reproduced artificially in a few minutes by the use of coagulants. Many waters

derived from upland areas, contain organic acid which may be present in sufficient quantity to cause plumbo-solvent action. Where waters of this class are dealt with by mechanical filters, it is usual to combine chemical treatment, for neutralizing the acidity, with filtration. This type of filter is very useful in cases where the head necessary is available, and the site for the filtration plant is restricted. They remove colour from the water to a remarkable degree and are therefore favoured in cases where water from a moorland catchment area is highly coloured, or where for trade purposes an absolutely clear water is essential.

In the United States of America, where water undertakings generally have not worked to so high a standard of purification as is general in Europe, and particularly in this country, water engineers were forced to the sterilisation of water by the use of hypochlorites in cases where the standard of purity was low. The chemical treatment of water found very little favour in this country until a few years ago, but, as in many other directions, the War has caused a considerable change in public opinion.

It may be safely said that chlorination saved the situation at the fighting fronts during the Great War. In previous campaigns enteric has been responsible for a greater number of casualties amongst the contending armies than the actual fighting operations. Consider for one moment the state of affairs in France and Belgium during the period of trench warfare. Here we had millions of men and animals crowded on a comparatively narrow strip of country so closely interlocked as to be incapable of movement. The existing wells, on the Northern side of the chalk area at least, were shallow and usually within a few feet of a cesspool, while the streams flowed over a soil initially highly contaminated. Add to these conditions the natural inclination of the fighting man to quench his thirst with the first water to hand, in the absence of any other liquid, and you have all that is necessary to produce a state of affairs which might be expected to make it impossible to maintain an army in being.

The success of chlorination was beyond all doubt. Water drawn from the most questionable sources was rendered safe by the addition of a small dose of chloride of lime, while more elaborate methods were applied behind the lines. In the result the losses due to water-borne diseases were almost negligible.

It is hardly yet realised that owing to special conditions imposed by the war, London has been largely supplied with chlorinated water during the last four years. As is well known, London obtains the

bulk of its water from the rivers Thames and Lea. The Thames water after abstraction from the river used to be pumped to large storage reservoirs, which are capable of holding a month's supply. The water thus stored was subject to sedimentation during this period, resulting in a very marked improvement in its purity from a bacteriological point of view. It was then passed on to the filter beds.

During the latter stages of the war, the cost of pumping the raw river water to the storage reservoirs became so great and the need for conserving fuel so urgent, that after successful experimental investigations it was decided to cut out the reservoirs and to treat the river water with chloride of lime on its way to the filter beds, thus eliminating all pumping. The results have been most satisfactory both from the point of view of the purity of the water and economy.

The treatment of water drawn from the river Lea has proved to be a more difficult matter owing to special causes, and considerable trouble was experienced in dealing with the objectionable taste acquired by the water. This has been almost wholly if not altogether overcome by a process of super-chlorination followed by de-chlorination by the use of sulphurous acid or a permanganate. Successful results have also been achieved with liquid chlorine as the sterilizing agent. This is a convenient process much in favour in the United States.

After three years' experience of the process, Sir Alexander Houston, the Director of Water Examination to the Metropolitan Water Board, definitely states that "the chlorination treatment has "been such a pronounced success that as long as there is a clear "economic gain by its use, it is most desirable that it should be "continued indefinitely as a post-war measure."

WATER SUPPLY OF LIVERPOOL.

The history of the Liverpool Water Undertaking is typical of that of many other large cities, and I therefore propose to sketch its development in outline.

The earliest supplies were derived from springs and shallow wells in the local sandstone, one of the most important being the Fall Well on the Common or Waste at the top of what is now St. John's Lane, from which water was carried by hand or in carts.

The first endeavours of the civic authorities to secure a piped supply from outside sources were decidedly unfortunate. About the year 1695, the Mayor, Bailiffs and Burgesses of the Borough concluded an agreement with three London gentlemen, granting to the promoters the right to construct works upon the waste lands and

commons belonging to the town and "to lay pipes, trunks, troughs "and other sort of aqueducts." These Londoners appear to have got the better of the representatives of the citizens, for some 15 years later, in the reign of Queen Anne, the Corporation obtained an Act of Parliament relating to the supply of water, and the recital to that Act contains a quaint account of the behaviour of the original promoters. The Mayor and his colleagues explain that the previous license was granted "upon the insinuation and assurances which were "made and given to them. . . . that they (the syndicate) could "and would at their own cost and charges bring or procure to be "brought into the said Borough of Liverpool good and wholesome "fresh water."

The document pathetically continues that they "never did any "thing towards bringing the said water. . . . so that the said "Corporation were deluded and have been greatly prejudiced by "colour of the said Agreement."

The Queen Anne Act empowered the Corporation to grant to Sir Cleave Moore the right to bring water into the town from springs on his own lands at Bootle; in consideration of this privilege Sir Cleave was to pay to the Corporation the sum of £10 a year on a 99-year lease. Unfortunately for the town, the performance of the worthy baronet was no better than that of the London syndicate.

Subsequent attempts to introduce water from Bootle were fruitless until 1799, when an Act was obtained authorising the formation of a Company by the name and style of "The Company of Proprietors of the Liverpool Waterworks." This Company, popularly known as the "Bootle Company," successfully constructed works and brought water into the town from springs on land belonging to the Earl of Derby. The original works were on a modest scale, as a single wooden main, 8 inches in diameter, was laid down through which water was forced by a 2 H.P. engine.

A second Company, which came to be known as the "Liverpool and Harrington Company," was incorporated by a private Act in 1822. The operations of this Company rapidly increased and eventually they obtained their supply from five wells in the new red sandstone in and around the town, the only one of which stations now in being is that at Windsor.

The existence of two rival Companies did not prove satisfactory, as they at first entered into keen competition and in some cases the main laying gangs raced each other along the same streets, each Company trying to outbid the other for the custom of consumers.

Afterwards an understanding was arrived at by which the area of supply for each Company was defined. While this prevented the earlier foolish competition, it enabled the undertakers to exploit the public. Under their Acts, the Companies enjoyed a monopoly of supply, and their shares rapidly appreciated in value, the original £100 shares of the Bootle Company being worth £380, whilst the Harrington shares rose to £610. Although the water supplied was of good quality, it was most inadequate in quantity. At the best, water was only supplied on alternate days, and then for not more than an hour or two. As was general at that time, the poorer parts of the town were supplied by standpipes, fixed in the courts, and the inhabitants had to carry the water and store it in vessels in their rooms. The hours at which water was turned on were, in many cases, most inconvenient, and sufficient time was not allowed to enable those requiring water to satisfy their wants.

This state of affairs, so unsatisfactory from a health point of view, continued for many years until the additional pressure due to another cause made an improvement imperative.

Liverpool became notorious for its disastrous fires, the water supply being such as to be practically useless for fire protection purposes. In one year alone, 1842, the value of property destroyed by fire, chiefly in cotton warehouses, was assessed at over £500,000, and the rate of insurance rose to the prohibitive figure of 25s. as compared with 4s. 6d. in London.

In 1843 the matter was therefore taken in hand by the Highway Commissioners, who promoted a Bill seeking powers to construct independent works. Owing to the opposition of the Companies, the Commissioners were prohibited from supplying water for domestic use and were restricted to a supply for public purposes, viz.:—watering the streets and extinguishing fires. The result of this Act was the construction of the great well at Green Lane, which is still famous for the quantity and quality of the water it yields. The powers of the Highway Commissioners passed to the Town Council in 1846, and then commenced a long and strenuous controversy as to the best source for a new and improved supply.

A numerous and powerful faction advocated the advantages of a supply from underground sources in the local red sandstone, whilst those in favour of a supply from outside could not agree upon the most suitable source.

Bala Lake, the River Alt and Rivington Pike all had their supporters, who engaged each other in wordy combat with the same energy as they

applied to the attempted confusion of the sandstone enthusiasts. Eventually the Rivington Scheme prepared by Mr. Thos. Hawksley was adopted, and in 1847 an Act was obtained authorizing the construction of large impounding reservoirs on the head waters of the Rivers Douglas and Roddlesworth in Lancashire, and the construction of an aqueduct terminating at the Service Reservoirs at Kensington.

By the same Act the Corporation was empowered to acquire the undertakings of the two Companies, and this was done at a cost of over £500,000.

Although the Rivington Scheme had been authorized and the land for works purchased, the opposition of the red sandstone partisans lost none of its keenness, and while the tide of battle between the rival factions swung backwards and forwards, no progress was made with the scheme.

After a controversy lasting more than two years, the Corporation appointed Mr. Robert Stephenson to enquire into and report on the question.

Stephenson's report issued in March, 1850, is a most able document and gives a well reasoned and decisive opinion in favour of the Rivington Scheme. The works were accordingly put in hand, and water was brought by gravitation into the town in 1857. The red sandstone stalwarts, though for the time being defeated, were as full of grit as their beloved rock, and force was added to their continued agitation by the high colour of the Rivington water when first introduced. The unfortunate engineer spent most of his time writing reports dealing with the complaints and schemes put forward by enraged and critical councillors or citizens.

One of the many suggestions he was called upon to deal with was as to the practicability of supplying both the Rivington and Well waters at alternating periods through the same line of pipes, so that the Well water should be available for drinking purposes, while the soft Rivington water should be reserved for sanitary and ablutionary purposes.

I ask you to imagine the task set to an engineer who has to regulate the supply in such a way that John Citizen is able to fill his morning bath with Rivington water, while the same tap is shortly afterwards called upon to provide Well water for the preparation of his breakfast tea or coffee.

Gradually the objectionable colour of the Rivington water disappeared as the bed of the reservoirs matured, and the water began to be appreciated at its true worth on account of its softness and purity.

It is an astonishing fact that although the supply from Rivington considerably more than doubled the resources of the undertaking, the town was again in the throes of a water famine within 10 years of the introduction of the new supply.

Relief was obtained by the construction of additional reservoirs and the purchase of compensation water at Rivington, also the extension of the wells in Liverpool, but it was several years before the case was correctly diagnosed and the cure applied by Mr. George Frederick Deacon, who introduced the now well known waste meter system.

Although the situation was improved for the time being, it was obvious that the existing resources must shortly be added to, and public opinion was again excited by a revival of the old controversy in all its former strength.

Schemes were propounded for supplies from the English Lakes, the Rivers Lune, Hodder, Wyre, Ribble, Clwyd, Dee and several of the tributaries of these rivers.

Even the survivors of the well men emerged from their retreat in the sandstone rock, and played a brave part in the battle of the sources both in the press and on public platforms.

The issue was narrowed down to the rival advantages of Lake Haweswater and the River Vyrnwy, and in 1879 the verdict was given in favour of the latter scheme.

It is not necessary for me to give any detailed description of the Vyrnwy Works, which were authorized by Parliament in 1880, and by means of which additional water was brought to Liverpool in 1891. Suffice it to say that this magnificent scheme was worthy of the City and placed Liverpool in the forefront of those water authorities who have made adequate provision for the supply of the first necessity of life. No one is better able than the Members of the Liverpool Engineering Society to appreciate the genius and skill of the engineers responsible for this great work, Messrs. Thos. Hawksley and G. F. Deacon.

THE CONTROL OF WATER SOURCES.

The question of Water Supply has received much attention during the last 50 years, and numerous Royal Commissions and Committees have enquired into and reported on the subject.

The first of these Commissions was that appointed in 1866, under the Chairmanship of the Duke of Richmond, for the purpose of enquiring generally into the best methods of supplying water to the large towns, and more particularly to the Metropolis.

A number of schemes were brought before the Commission, the chief of which were Mr. Bateman's proposal to obtain a gravitation supply for London from the head waters of the River Severn, and that of Messrs. Hemans and Hassard for a supply from the English Lakes.

Mr. Bateman's scheme involved the construction of several large impounding reservoirs in North Wales, and it is interesting to note that one of these was to be on the identical site of the present Lake Vyrnwy.

The rival scheme of Messrs. Hemans and Hassard chiefly depended upon water to be drawn from Thirlmere, Ullswater and Haweswater, and here again some of the areas chosen have since been appropriated by other Authorities, as Manchester obtained powers in 1879, which have since been exercised, to take water from Thirlmere, and last year successfully promoted a Bill for the development of Haweswater.

Although the recommendations of the Richmond Commission did not result in the actual construction of works, they enunciated three principles which have had a material effect on all subsequent legislation relating to water supplies. The final report of the Commission in 1869 contains the following recommendations:—

(1) "That no town or district should be allowed to appropriate a source of supply which naturally and geographically belongs to a town or district nearer to such source, unless under special circumstances which justify the appropriation."

(2) "That when any town or district is supplied by a line or conduit from a distance, provision ought to be made for the supply of all places along such line."

(3) "That on the introduction of any provincial water bill into Parliament, attention should be drawn to the practicability of making the measure applicable to as extensive a district as possible, and not merely to the particular town."

Further investigations from the point of view of particular interests in the water resources of the country were made by succeeding Commissions and Committees, amongst these being the Rivers Pollution Prevention Commissions of 1865 and 1868; Royal Sanitary Commission, 1868; Select Committee on Conservancy Boards, 1887; Royal Commission on Sewage Disposal, 1898; Royal Commission on Salmon Fisheries, 1900; Royal Commission on Canals and Waterways, 1906; and the Select Committee on Water Supplies Protection Bill, 1910.

Generally these Bodies found that it was impossible to divorce one

interest in the water resources of the country from the others, and their recommendations all indicate clearly the necessity for a Central Controlling Authority, whose duties should include the following :—

(1) The allocation of water for all purposes.

(2) The collection of information and statistics regarding water resources.

(3) To advise all tribunals dealing with applications to appropriate water.

Beyond question, the water resources of the country have not been utilised to the best advantage. Water Authorities have, in many cases, been allowed to appropriate water producing areas far in excess of what they are likely to require within a reasonable time, whilst other neighbouring communities are in desperate need of additional supplies. The claims of River Authorities and riparian interests, as regards compensation water, have often resulted in extravagant amounts being allocated to the stream. The construction of reservoirs on the upper reaches of rivers and their tributary streams has had a most beneficial effect in equalising the flow of the stream. Vast quantities of water which formerly passed down the stream during times of flood, submerging valuable agricultural land and causing serious damage, are now retained in the reservoirs, while the scanty summer flow is greatly increased by the compensation water discharged from the reservoirs. It is safe to say that had the disposal of the total quantity of water available been considered from all points of view, and a fair division made between the various interests involved, a considerable amount of water now passed down the rivers could have been more profitably used for the supply of large communities. On the other hand, in manufacturing areas, such as Lancashire and Yorkshire, important trade interests exist on many of the streams, and proper provision must be made for their preservation. It is, however, difficult to believe that the best use is being made of the resources of the district when one sees the clear, bright water, within a few hundred yards from the point at which it is discharged into the stream, so grossly and heavily polluted by trade wastes as to be useless for any purpose whatsoever. Circumstances such as these have led to a curious innovation in the case of Sheffield, where Parliament has recently sanctioned a scheme under which Sheffield is to pump a certain quantity of purified water drawn from the river Don below the town, up to the foot of the reservoir above the town, where it is to be discharged into the river in lieu of the compensation water hitherto provided by the reservoir, thus retaining for the supply of the town an equivalent quantity of pure water.

The recommendation of the Richmond Commission of 1866, as to the provision that should be made for the supply of authorities along the line of aqueduct, although sound in principle, has led to many anomalies. In fact, cases have been known in which an authority promoting a water scheme, has been faced with claims on the part of river interests and local authorities on the line of aqueduct amounting in the aggregate to more than the scheme is capable of producing. By the pressure which opposition to the proposals of the promoters is able to produce, many local authorities have obtained clauses or agreements for the supply of water from a trunk aqueduct passing through their area, and have allowed their powers to lie dormant for many years. In respect of this valuable right no payment has been made, the undertakers having to bear the whole of the expense of constructing the works and remain under the continued obligation to supply large quantities of water at any time it may be demanded.

The Manchester Waterworks Act of 1919, marks a great advance which will go far to prevent such an unjust state of affairs. In the first place, the compensation to be paid to the rivers is fixed on a very much lower basis than has been general, and some elasticity has been given to the arrangement by providing for a variation in the amount of the compensation water under certain conditions.

An equally important step has been made as regards the supply to local authorities on the line of aqueduct. A certain proportion of the available yield of Haweswater, after paying compensation to the stream, is to be ear-marked for such supplies in bulk, but authorities claiming a portion of the quantity so ear-marked are required to declare beforehand whether they intend to take the supply or not, to specify the amount, and also to show that their local resources have been fully developed. The quantity allocated is to be paid for whether taken or not, and the price at which such supply is given is to be based upon the local authorities share of the capital cost of the works in proportion to the amount of water taken.

The Manchester Act is likely to form a precedent, and undertakers will now be able to go forward with their schemes, knowing what outside liabilities and obligations they are likely to be called upon to meet.

The latest enquiry arose out of the decision of the present Government to investigate the possibilities of developing the water resources of the country for power purposes. This Committee, under the Chairmanship of Sir John Snell, has already presented two Interim Reports.

The first, issued in February, 1919, is almost wholly concerned with the possibility of establishing hydro-electric stations in Scotland. It outlines particulars of nine suggested water power schemes, together capable of generating a continuous supply of 183,500 electrical horse power, corresponding to an output at the stations of 1,200 million Board of Trade units per annum. When it is pointed out that this available energy is equivalent to more than one-quarter of that generated by the whole of the public steam power stations in Great Britain in the year 1917-18, the magnitude of the water power available will be better appreciated.

The report states that upon the basis of present average practice at coal-fired stations, the nine potential water powers represent the equivalent of 1·85 million tons of coal per annum.

After making full allowance for all losses in transmission and transformation, the schemes already investigated when fully developed would be capable of supplying about double the present output for power, traction and lighting purposes in Scotland.

It is estimated that this power could be developed at an average capital cost of less than £40 per effective electrical H.P. developed at the water stations, which compares very favourably with the limit of cost necessary to compete with the best steam power station. North Wales possesses great water power resources, which have already been developed to some extent for manufacturing purposes, and considerable extensions are likely to be made in the near future.

At an early stage in the investigations of the Water Power Committee, it was realised that it was impossible to separate the water power question from the other water interests, and their terms of reference were enlarged so as to ensure that the water resources of the country are properly conserved and fully and systematically used for all purposes.

The second report of the Committee accordingly deals with the control of the water resources of the country and reviews the position under the following headings :—

- (1) Public supplies for domestic and trade purposes.
- (2) Industrial purposes.
- (3) Canals and navigable waterways.
- (4) Power.

The findings of the many previous Commissions and other bodies as regards the control of resources are endorsed and emphasised, as Sir John Snell's Committee places in the forefront of its conclusions a recommendation advising the establishment by Act of Parliament

of a controlling Water Commission, having jurisdiction over England and Wales, and armed with certain statutory powers and duties which will ensure the allocation of all water resources in the general interests of the community.

The need of such a controlling body has been long felt, but it is unfortunate that the proposal has been brought forward at a time when the country is anxious to throw off the many forms of Government control which war conditions have imposed, and it is to be feared that nothing will be done until public opinion on this point has changed.

In a small, densely populated country with immense industrial interests, such as England, the day has long gone past when the water resources can be squandered. The counties in the South, South-Midland and Eastern areas chiefly depend upon rivers and underground sources for their supply. The amount of water that can be obtained from wells in the chalk formation is limited in each case, and although rivers have in the past yielded and still continue to supply vast quantities of water, many of them are unsuitable for domestic supplies, and in respect of the remainder the time can be foreseen when further abstractions will be impossible owing to the requirements of other interests.

In the Midlands, several large communities have already gone outside their borders for supplies. Birmingham has a solid footing in central Wales with her splendid scheme in the Elan Valley, whilst Nottingham, Leicester and Derby are partially dependent upon the Derwent Valley works. North Wales has already been called upon to furnish a supply to Liverpool and Birkenhead, whilst other demands are likely to be made on this area in the near future. South Wales has large communities of its own, and is jealously watching the covetous glances which are naturally being cast towards her hilly districts by authorities in the South and South-Midland districts.

The busy industrial areas in the North have for many years drawn heavily on the gathering grounds on the slopes of the Pennine Range, whilst Manchester has a firm grasp on certain of the natural reservoirs in the Lake district. Ullswater is the only large lake at a sufficient elevation to afford a gravitation supply at a distance which has not been appropriated. The magnificent sheets of Windermere and Derwentwater are at too low an elevation to work in with a gravitation supply. In my opinion, the time is not far distant when the dense populations of the North will look towards the vast resources of Scotland, and it does not require any fanciful stretch of the imagination

to picture great national aqueducts running South from Scotland along the high ground forming the backbone of the North of England, from which the great manufacturing districts on each side will draw their supplies.

Much remains to be done in connection with the supply to rural areas, and in all directions the need of co-ordination and control is evident.

A striking example of this is to be found close at hand. There are in South Lancashire a number of contiguous authorities, nearly all of which are to-day practically at the limit of their local resources, and singly are not sufficiently powerful to obtain a new supply from outside sources. Most of them are inclined to adopt the attitude popularly described as "sitting on the fence," trusting that the urgency of the situation will drive one or more of their neighbours to promote a scheme. In this event the fence will be speedily deserted and all will be clamouring for their share of the spoil.

This is essentially a case for co-ordination and co-operation, as a scheme sufficient for all their requirements can be carried out on a partnership basis, which is impossible to any one of them alone.

I lightly embarked on this address with the intention of dealing generally with the work of the hydraulic engineer, and now find that beyond a brief reference to development of the water for power purposes, I have almost entirely confined my remarks to Water Supply.

I believe that hydraulic engineering offers one of the most interesting and promising fields to the young engineer who has acquired a thorough scientific training, and in this connection I wish to quote and endorse a paragraph contained in the first Report of the Water Power Resources Committee with regard to training. This is as follows:—

"Strong evidence has been submitted to the Committee regarding "the lack of adequate training facilities in the Universities and Technical Institutes of the United Kingdom for young engineers wishing "to enter the field of hydro-electric development. In view of the "very large extension of water power development that is practically "certain to take place in the near future, both in this country, in the "British Empire, and in other countries, the Committee considers it "important, in the interests of British industry, that steps should be "taken to remedy this state of affairs."

I have always thought, and I believe with some reason, that the work of the hydraulic engineer most closely fits in with that grand definition of the profession of a Civil Engineer contained in the

Charter of our parent Institution—"The art of diverting the Great "Sources of power in Nature for the use and convenience of man."

Mr. WILLIAM BRODIE, Past President, said that he had, as they all had, he was sure, listened to Col. Davidson's Address with great pleasure. The subject chosen, the supply of water to large communities, was one of which the President was complete master, and all would agree that the Address was a model one for such an occasion, the subject being treated comprehensively and in a most interesting manner, lightened as it was in delivery, from time to time, with those casual gleams of humour of which the author of the Address was a master. The references to Biblical, Roman, and other early times, conveyed information of which not all of them had been aware. The conditions in Britain now, with pollution in every stream passing through or near populous localities, was very different from earlier days when the streams were clear and wells free from contamination. Liverpool had from time to time, as her community grew, sought and secured provision for the needs of its people with a sufficient degree of foresight, and in his own time, there had been several keen and wordy battles over wells and catchment areas. It was a very happy thing for the district that the supply of water actually provided was most excellent in quantity and quality, and there was no doubt that in the hands of their President, so far as the question lay there, the needs of Liverpool in this commodity were and would be fully safeguarded. They were to be congratulated on having as their President for the year one of the foremost engineers in his branch of the profession. He proposed that a hearty vote of thanks be accorded to the President for his Address, and that he be requested to allow it to be printed in the "Transactions."

Mr. W. J. WILLETT BRUCE, Past President, said that he had very much pleasure in seconding the resolution. He was sure they were all gratified at Col. Davidson occupying the Chair as President of the Liverpool Engineering Society. He felt assured that he would admirably acquit himself in discharging his Presidential duties and so maintain the high reputation of his predecessors. He was quite satisfied that whatever the weather conditions were, they could always rely on Col. Davidson to ensure a good water supply, and he hoped that they would never go dry. He was sure that they would all be most gratified if the Presidential Address could be added to the former ones by being inserted in the Society's "Transactions."

The resolution was then put to the Meeting and carried by acclamation.

The PRESIDENT, in replying, said that he must thank Mr. Wm. Brodie and Mr. Willett Bruce for the more than kind way in which they had proposed and seconded the vote of thanks, and those of the Members of the Society who were present for the patient hearing they had given to his Address. As he had already explained to the Council he realised the great difficulty, if not the almost impossibility, of interesting the Members of the Liverpool Engineering Society in the subject of water. He would esteem it a great honour to have that Address of his included in the "Transactions." There was one matter to which he wished to refer. He had been present on the previous evening at the meeting of the Institution of Civil Engineers, when Mr. John Brodie was elected to the Presidential Chair and read his Inaugural Address, and he thought, that from his point of view, it was a happy coincidence that he should be President of the Liverpool Engineering Society in the same year as his distinguished colleague and former President of their Society, Mr. John Brodie, had received the "Blue Riband" of the Profession.

17th November, 1920.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,

President, in the Chair.

The Council reported that the following elections had been made ;—
WALTER HENRY KEANE GYLES, B.A. (*Cantab.*), ALFRED HALF-WHITE, M.A. (*Cantab.*), GEORGE LAIRD LYLE, ALFRED HOWARD READ, M. Eng. (*L'pool*), HARRY SILCOCK, ALEXANDER SMELLIE, HENRY AMBLER WHITAKER, B. Eng. (*L'pool*), and EDWARD REGINALD CORKER WILLIAMS, as *Members* ; JOSEPH RAWLINSON, STEPHEN MELVILLE SCOTT RAM, B.A. (*Cantab.*), and ERIC NOEL STERN, as *Students*.

"The Prevention of Accidents in Industry."

BY C. K. ATKINSON.

THE question of prevention of accidents in the workshops of Britain is at present absorbing the attention of employers in the mass, and some of the foremost Captains of Industry are exhibiting keen interest in the development of the "Safety First" idea which appears to have become so firmly established all over the United States.

Despite the various enactments which, for many years past, British legislation has from time to time introduced, and the many statutory regulations in connection with the Factory Acts (the proper observance of which is the object of the periodical visits of H.M. Factory Inspectors to all industrial workshops), it is to be deplored that many employers and supervisors in the past have neglected to take due note of their suggestions and expert advice, as regards the fencing and safeguarding of machinery, until their attention has been forced by the occurrence of some serious accident to an operative which, in its general effect, has proved to have endangered the morale of the whole department or workshop, and as a consequence efficiency and production have been seriously reduced.

It should be borne in mind by every industrial supervisor, and indeed by everybody concerned, that no precaution should be omitted to guard against accidents under any circumstances. To accomplish effectively this desired end it will at once be apparent that hearty co-operation between managers, foremen and workpeople must be exhibited.

It should be the first care of all concerned to see to the proper guarding of driving belts, driving wheels, shafting, and machine parts of all machinery within their sphere of action. Accidents of whatever degree are a serious matter and more attention should be paid to the alleviation of consequent suffering than has hitherto been accorded in years past. Every broadminded thinking man must know that the unfortunate victim of the accident is not the only sufferer therefrom.

Nowadays one's attention is often arrested by the warning—STOP! LOOK! LISTEN! How often does one pause to consider the portent of the challenge or even give thought to the misery a single accident brings in its train to those dependent on the victim.

It is first necessary to take into consideration what an accident means to a worker, particularly if he be wholly incapacitated. It is to be feared that very often one is apt to take no further interest than to assume that the patient is all right simply because he is receiving skilled surgical treatment and will be entitled to receive pecuniary compensation under the Workmen's Compensation Act. But this represents only the initial part of the case. Assuming that the man has a wife and young family dependent on his weekly wage—they in turn suffer—for it must not be forgotten that the amount of accident compensation, being at best only half of the average earnings, very often proves to be insufficient to procure the bare necessities of life. Then, again, there is the loss to the firm of an experienced worker and, in its turn, production suffers.

When the loss in wages to the workman and the consequent suffering to his dependents, plus the loss to the employer of the workman's output is considered, it will be evident that a grain of prevention is worth any amount of cure.

It will no doubt be agreed that where a family is reduced by privation, the consequent lowering of vitality affects the general health and renders its members more susceptible to the danger of contracting disease, consequently it is not very difficult to imagine how widespread and far reaching may be the result of a single accident.

Many accidents in the past have been caused by carelessness, thoughtlessness, or indifference on the part of the worker in failing to comply with definite instructions, whilst again many have been the direct result of slackness on the part of the foreman or supervisor in failing to instruct and initiate the worker in the manipulation of the machine he has been entrusted to operate, or in many instances the failure on the part of the employer to provide suitable Safety Appliances.

Every machine minder or operator should have a card hung conspicuously on his machine giving in effect some such instructions as the following :—

The person whose signature and tally number appears on this card is the only one authorised to work this machine.

Any other person working or otherwise interfering with this machine, except with the knowledge and consent of the foreman of the department, will be liable to instant dismissal.

The signing of this card will imply that the person concerned has been shown how to manipulate this machine and any safety appliances thereto.

Signed

Date

Into all factories should be introduced Safety Committees, which should be made up of a number of employee representatives together with an equal number of responsible persons representing the firm. The duty of such a Committee should be to inquire into the causes of accidents and also (in co-operation with the management) to suggest remedies calculated to prevent recurrence.

Following the occurrence of an accident caused by machinery or otherwise, the Committee should seize the earliest opportunity of proceeding to investigate the circumstances on the spot, at the same time the men engaged on the work involved should be assembled and all the circumstances surrounding the accident should be fully discussed with a view to ascertaining the best means to adopt in order to avert a repetition. A report should be drawn up by the Committee, a copy of which should, in due course, be posted up on the Works Notice Board for general publicity.

It has been found in certain large factories that these methods have proved very successful and have been the means of stimulating and encouraging the workpeople to increased care on "Safety" lines, in addition to which many valuable suggestions have been the direct outcome.

In this connection, a system of suggestion boxes provided with specially prepared forms and envelopes, and placed in suitable positions throughout the works, have proved of immense value.

The boxes are clearly indicated by a poster inviting the suggestions of all employees who may have ideas which, if put to practical test, might tend to improvement in methods of working, of making for safety, or of any other matter in connection with their daily occupation which will prove beneficial to the Company or the Employee.

The poster surmounting the box should be made as striking and attractive as possible, e.g. :—

Never mind how small the Suggestion—it is exercising your inventive faculties, and, with practice, you may one day strike a valuable idea.

ALL accepted suggestions receive suitable awards.

Suggestions which save time, save material, save energy, produce better work, or add to the comfort of the worker, WILL BE APPRECIATED.

Procrastination is the thief of time. Don't let this apply to you regarding that suggestion you have in mind.

The Box is below.

Lest we forget ! There is always room for one more suggestion in the box below.

WANTED—SUGGESTIONS.—We appeal now to each department ; so up and get going.

Everyone should try. It only needs starting.

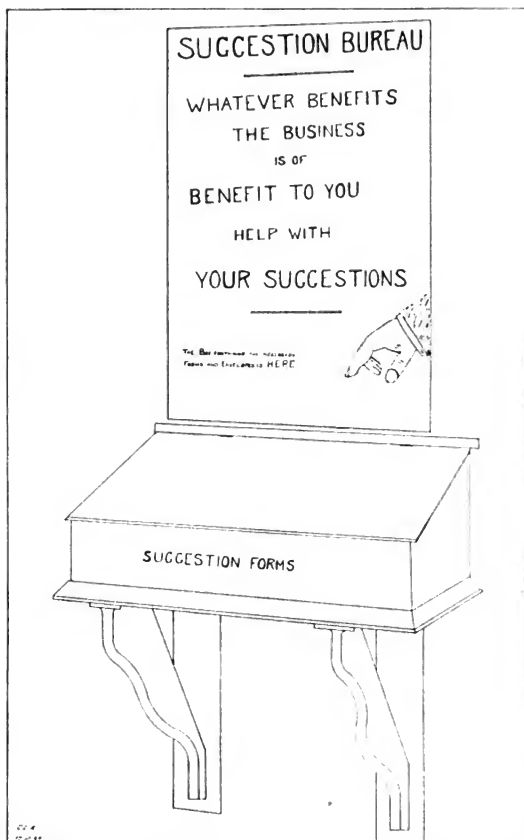
Keep this in mind : Simple suggestions have often proved to be most valuable.

The Box below is ready to receive yours.

We need your help for improvement. Your ideas, if adopted, will be rewarded. Now's your chance.

Let us have your ideas. It is always to your interest to do so. Do it now.

The Box containing the necessary Forms and Envelopes is here.



Periodical inspections should be made by the Committee of all parts of the factory and workshops and careful examination made of machines, machine guards, materials and implements, and report made on the conditions found. This report, having been duly signed by the Chairman of the Committee, should be forwarded to the general management for attention and consideration. Similar measures carried out in at least one large factory, have accounted, in the course of a very few years, for the reduction of accidents by something like 65 per cent.

It is necessary in order to meet the requirements of the Workmen's Compensation Act, that an up-to-date Ambulance Brigade be established—members of which should be appointed to the various departments, where notices should be exhibited announcing the name of the member appointed and where he or she is to be found—the name of the next available member should also be given, to be called upon when necessary.

Every factory should be provided with one or more surgeries according to the numbers employed—under the supervision of a trained hospital nurse. All accidents, however trivial, should be reported, whilst members of the works ambulance brigade should be instructed to render "First Aid" only; all redressings to be attended to by the hospital trained nurse in the surgery.

Many persons sustain trivial accidents such as cuts, scratches, &c., in the course of their daily occupation, and apparently think nothing about it, they fail to realise the importance of having all wounds attended to immediately—notwithstanding the fact that every facility is given to receive first aid and is placed within easy reach and at the disposal of all.

What are the reasons for the immediate care of wounds—wounds inflicted accidentally it may be, with all manner of instruments and tools, often contaminated with dirt and through skin which, owing to the nature of the work in hand, is more or less soiled.

When such skin is lacerated, no matter how trifling the injury may be, foreign matters permeated with microbes are introduced, and unless promptly checked by sterilization (effected by the dressing of the wound with an antiseptic) the germs very rapidly develop and septic poisoning results. Harmful bacteria are formed in dirt everywhere, therefore whenever and wherever dirt enters a wound there is danger of infection: with these facts in mind should it be necessary to urge all workers to seek prompt aid for all wounds?

Many accidents reported to H.M. Inspector of Factories in the

past might, in all human probability, have been reduced to trifling insignificance, had the workers concerned taken the trouble to have their injuries attended to immediately they occurred.

Statistics compiled in a certain large factory show that 70 per cent. of the accidents for a given year were due to failure on the part of the human element.

In many cases there is proof of the axiom "familiarity breeds contempt." A worker on a machine will take minor chances so often with success that he begins to feel there is really little or no risk, till one day he is caught napping—just a trifle slower than usual it may be—and before he has time to realise it the tip of a finger is nipped or it may be worse. Again, there are cases where men have leaned over revolving shafts, to adjust a belt perhaps, regardless of the fact that a loose jacket was apt to get wound up by the shaft beneath.

Any worker known to be a habitual risk taker should be dealt with drastically as a precautionary measure to others, as the force of example being irresistible he would be certain to find others to try and emulate his risks, apart from the fact that he would always be a constant source of anxiety on his own account.

Another important matter is the question of endorsing men's records with particulars of accidents due to pure negligence or gross carelessness, &c. In such cases the worker should be advised of the fact that such an endorsement has been recorded and at the same time assured that every opportunity will be afforded him to "make good."

If an employee gets it into his head that he has been "black-listed" without hope of redemption, any interest which he may have had in his work must surely diminish for that very reason, as it is scarcely human for a man to give of his best whilst feeling that it is of no avail so far as his own prospects of advancement are concerned.

Unless this idea is dispelled it can only tend to make the workman concerned careless and indifferent or deceitful, and would be very apt to have a bad influence on fellow-workers, and liability to accident will become more pronounced.

If the worker makes good progress he has every right to be credited with his efforts, and it should be made known to him that he has, through his own exertions, regained his footing in the estimation of those in authority over him.

If, on the other hand, a worker shows no improvement it is quite unfair to both worker and employer, and also to those who might come under the sphere of his influence—to retain his services, he being

nothing more than a menace to the well-being and harmonious working of his department and a source of worry to the management.

It has been stated by Lord Leverhulme that :—

“Anything that gives commercial undertakings a more efficient staff and a more economic method of working will be an equipment for winning the industrial war, after we have won the military one.”

It will be self-evident that anything calculated to conserve man power will make for efficiency and economic working, and “safety” methods, properly applied, will assuredly achieve this object.

Conversely—what can be more extravagant or wasteful than the loss of man power through preventable accidents?

Yet what are the facts? During the year 1919 there were 1,384 fatal accidents reported as having occurred in the factories of this country—whilst about 125,000 persons were so seriously injured as to entitle them to compensation under the Workmen’s Compensation Act, approximately about one-third of these were accidents due directly to machinery.

No doubt many were unavoidable under existing conditions, but the record as it stands gives one food for thought and shows what a wide scope remains for improvement.

When these figures are realised, what a tremendous economic loss they represent in the aggregate both to industry and to the community!

It has been found in certain extensive workshops that the attitude of the workman towards “Safety” depends largely on the attitude of the foreman. It has been observed that a foreman who is convinced of the efficiency and practicability of “Safety” work, and who by word and example carefully impresses his men with his convictions in this respect, soon exerts a powerful influence which is reflected by “Safety” habits becoming general almost as a matter of course amongst his men who, be it noted, are not slow to observe where their own interest lies and show their appreciation of the fact that he is doing all in his power to protect them by following his lead.

Now with regard to the matter of posting “Safety Bulletins” on the Notice Boards. It is obvious that if it is desired to impress a man with the value of a particular idea, one cannot do better than by bringing it constantly before his notice, at the same time carefully maintaining his interest. So, in keeping the Notice Board furnished with a frequently varied and interesting bulletin, it will be seen where the advantage lies.



THOUGHTS FOR THE DAY.

REMEMBER

MACHINERY IN MOTION

is always ready to

BITE ——— YOU !

—————
DON'T LET IT.

—————
Read the Safety Notices.

—————
ONCE IS ENOUGH.

Investigate every accident that happens in a department, and try to prevent an accident occurring in like manner.

This is the object of the Safety Committees.

—————
THE MANAGEMENT SAYS :

It has always been claimed that "it takes two to make a quarrel."

We won't quarrel with you for taking an interest in Safety Work.

—————
CARE.

Want of care does us more damage than want of knowledge.

ACT WISELY.

Report unsafe places to your foreman or manager.

Health and Strength are better than wealth.
SAFETY HABITS will help to keep them.

Accidents are avoided by careful and thoughtful application throughout our daily work.

WOUNDS.

Septic wounds, however slight, require careful treatment. Have them dressed daily in the Surgery.

Satisfy yourself that you are safe.

Always be on the look-out

For danger zones.

Enthuse your fellow-workers

To be careful.

Your efforts will be rewarded.

For now is the time

Inspiration is needed,

Requiring every care to

Save suffering and loss of wages

To all industrial workers.

"CARRY ON."

It may not be out of place here to emphasise the importance of one or two rules with reference to the guarding and fencing of machinery.

Where all reasonable precautions have been taken it will be found that accidents—though numerically in less degree—will still happen—and it is on the apparently trivial ones that special care should be taken to have them dressed at the earliest possible moment, as there is little fear of those of a serious nature being overlooked.

The British Industrial Safety First Association is now established in this country for the purpose of systematising safety methods and introducing them into all workshops—this laudable and humane object is actively supported by the Home Office. Many of the large firms have become members, and judging by recent reports, the notices issued by the Association have been the means of educating large numbers of workers in safety methods with the satisfactory result that in many instances accident rolls have been reduced by 50 and 60 per cent.

All employers of labour should take the opportunity of becoming active members of this Association, and it will be found that from any point of view such membership will prove one of the best assets possible to introduce into any workshop.

The Paper was accompanied by two diagrams which are reproduced in the text, and was illustrated by lantern views.

DISCUSSION.

The PRESIDENT said that they had listened to a short but interesting paper, which he thought bore important evidence of the broadening of the scope of their Society within the last few years. He was of the opinion that before the war they would have thought it very unusual to have had a paper on such a subject as they had had that evening. It was not quite new ground for them, as they would remember that quite recently a paper had been presented on Welfare Work which followed very closely the paper of that evening. It showed that they were broadening their outlook in having subjects of that kind brought before them. It was quite evident that the author was an enthusiast in connection with the subject he had been speaking to them about. Personally he thought that the author had prepared his paper with the deliberate intention of provoking a discussion. He took it that those views had been put forward not only from a humanitarian point of view but as a sound business and commercial proposition, and he felt sure that the members present would wish to give the author a hearty vote of thanks for reading the paper. The President

Mr. J. HAMILTON GIBSON thought that it was really a very important thing that men should be impressed with the idea that it was extremely important that they should not only look after themselves but their fellow workmen, because, very frequently, the accidents affected not only the man himself but involved a number of others. He was not sure, however, that the methods that were being adopted in such places as big shipbuilding and engineering establishments were quite the best way of going about it. The men, and the boys especially, looked upon these placards in anything but a serious spirit. He thought that it was a good thing to make the notices as attractive as possible, and, if it was at all possible, to impart a little humour into the texts and the pictures. The word texts reminded him that he knew of a good many of their young people who looked upon these placards in the nature of Sunday School warnings, and he was afraid that even these were not always as effective as they might be. Taking the paper more in detail, on page 23, he thought that the suggestion that every machine minder or operator should sign a card, which would be hung somewhere near his machine, was excellent. In that case the foreman or the supervisor would have to see that the instruction was faithfully carried out. Mr. Gibson

Mr. Gibson These instructions were often very good in themselves, but they failed just because there was no one there to insist that the instruction should be observed. Some years ago, in closing up turbines, it frequently happened that although the turbine had been thoroughly well searched, lest objects such as nuts, chisels, and sometimes even files, had been left in with the consequent danger of wrecking the turbine, such pieces did sometimes get overlooked in odd corners and parts. Of course, in that case, there was not the same danger to the individual, but it was a very costly matter if anything fouled the blades, and he had inaugurated a system whereby the man who closed up the turbine signed a form to the effect that he had actually searched every part and as far as he was aware there was no obstruction left in. They had, however, the greatest difficulty in keeping that system going. They sometimes found that a turbine was closed up and the man had not troubled to sign the document, but it was quite a good system, because it impressed upon the responsible person the fact that he must be careful. He thought that it was quite a good practice that a short report of an accident should be posted up in the works, not necessarily giving the name of the man, but as a warning that such an accident had occurred. On the same principle, they could see any day down at the landing stage the warning that a passenger had been fined 40s. for attempting to jump on board a ferry steamer. He was not quite sure as to the value of suggestion boxes. He was afraid they were looked upon very largely with suspicion among the men. If they had a good idea, and if it was at all valuable, they were not at all likely to put it into a box, because they did not know who was going to get hold of the idea. On page 24 they would find a number of "suggestion" notices. He was inclined to think that the men and boys he had come in contact with were not very much impressed with these incentives. They would much prefer to bring the suggestion to the foreman or manager rather than to a committee with whom they were unacquainted. Then again, on page 27, he did not think it was a wise thing to endorse men's records in such cases.

Mr. Atkinson stated—"Another important matter is the question "of endorsing men's records with particulars of accidents due to pure "negligence or gross carelessness, &c. In such cases the worker should "be advised of the fact that such an endorsement has been recorded, "and at the same time assured that every opportunity will be afforded "him to 'make good.'"

That rule required to be handled with a considerable amount of tact. It did not do to blacklist a man, or let him know he was black-

listed. Some little time ago he had heard of a case of a man, who, Mr. Gibson acting on the invitation, dropped a suggestion into the box. He had been in the habit of carrying buckets of water to a certain part of the works, and he suggested that a tap should be provided nearer to the place. He received a guinea for his suggestion but got the sack the next week. It was found that he could be done without. As regarded automatic safety appliances, he thought that they were to be looked upon with a certain amount of suspicion. There was a natural tendency to assume that all such automatic appliances were infallible, and people were apt to attach too much importance to them. He had known automatic safety appliances to fail after many years. He knew of a man, only a few weeks ago, who stepped into an automatic lift when it was not there and fell down the shaft. Luckily he escaped without injury, but it ought to have been impossible for the door to open when the lift was not there. He cordially agreed with the author when he said, "All employers of labour should take the opportunity of "becoming active members of this 'Safety First' Association, and it "will be found that from any point of view such membership will prove "one of the best assets possible to introduce into any workshop." Anything that could be done to make conditions of working better and safer was all to the good.

Mr. H. S. ROWE remarked that since the author had taken up that Mr. Rowe work and specialised in it undoubtedly very good results had been produced. It might be that some of the posters appeared to the men more or less humorous, or even childish, but as a matter of fact interest had thus been provoked, which showed that employees had had their attention arrested. He did not know whether he was giving away a little secret or not, but in his own department the most serious accident that had happened this year had been due to a man catching his head against a "safety first" sign attached to an automatic rail guard. He thought the matter of suggestions should be taken up seriously, because there was an enormous amount of enthusiasm and brains which might be relied upon to bring them forward. The main point in the whole of the idea underlying suggestions, was that the workman must feel that his suggestion was properly appreciated, that he would be duly recompensed, and that it would not be exploited against him. A little while ago there was a letter in one of the engineering papers, from a Brussels firm, in which it was stated that a suggestion campaign had been started in their works, and a rule had been made that for every adopted suggestion the reward to the man would be the value of one year's saving to the employer. If such a scheme was adopted generally

Mr. Rowe it would produce a valuable flow of suggestions, as it involved a definite scale of reward for the man who made them. Quite a simple suggestion might be very valuable—the cutting of a door through a wall, putting castors on wheels, or making cupboards to open a different way, and if a known basis was worked from for rewarding, he thought that worthy suggestions would follow. The charts with which the author concluded his paper were, he believed, reproductions of actual conditions in the works the author was engaged in. These works were certainly one of the best—if not the best—in the country, for the prevention of accidents, so that when they were told that even here a 60 or 65 per cent. reduction was obtained it surely followed that there was a very great field to be covered with a correspondingly great reward to be gained by a more general adoption of the “safety first” idea.

Mr. W. Brodie Mr. WM. BRODIE considered that the subject was a very interesting one, not merely to those who were interested in workshops but other branches of engineering in which many members of the Society were interested. These other branches might learn lessons from what had been said that evening. It struck him as very strange that within a week of the time when hundreds of thousands had passed the Cenotaph in Whitehall, which was a memorial to thousands of British people and which also represented the loss of millions of workpeople, that the saving of the end of a finger, or possibly, in the extreme, a life, might be thought so important as to be brought before an Engineering Society. It certainly threw a strange light on their civilization that could allow such things as war to occur when they troubled about these very minor things affecting one or two. He had great sympathy for any measures that were adopted in factories, workshops, or otherwise, for the safety of the men. He had come into contact, very largely, with the officials of different departments of the Home Office, and he had always found them to be very reasonable and that the requests they had made were well worthy of attention. They refrained from pressing or even from making suggestions which would be uncalled for, or would be unwelcome in the best sense to the good employer. Therefore they were always glad to facilitate their work and to take action in any case where they had called for some amendment. He thought that the author had rather taken away from the portion of his case making appeal to employers when he said that in a certain large factory 70 per cent of the cases were due to the carelessness of the men themselves. That, of course, was probably a special factory, but there was no doubt in the minds of any who knew anything about it that a great

many of the accidents were due to the men themselves, and especially the young men, who were larking and put their hands on the machinery. A very great deal of good was done in these places by a careful foreman, who looked after his men like a father and did all in his power to prevent accidents. He knew foremen carrying out most difficult and dangerous operations, who had gone through a long series of years without any man being killed or seriously injured in the work that they had undertaken. The foreman had to be a man who supervised and looked after the men, and the good foreman's motto in properly conducted works had always been "safety first" for the men. Accidents had happened there due, very often, to the men thinking their own way about things. There was only one criticism which he had to make. On page 29, the author had "Thoughts for the day." "Remember machinery in motion is always ready to bite you." He did not like that sort of thing; it came from the other side of the Atlantic. He did not think it was suitable for their surroundings. It was somewhat of a "yellow-press" touch and he would prefer to use simple straightforward English of the ordinary style—"keep clear of the propellers." Everybody understood that. They did not say the propeller was going to bite them. The machinery was not going to bite them. He thought it was a sort of American slang that would be better left out of such notices. "Satisfy yourself that you are safe; always be on the look-out for danger zones; entuse your fellow-workers." Was that English? Was there an English verb "entuse"? There was a great fashion nowadays for these extraordinary notices, which he would rather see substituted by good English.

Mr. W. Brodie

Mr. G. W. DANIELS observed that he could not claim to be an expert in that particular line, although he was connected with the same works as the author. He had previously been at works where nothing of that kind had been attempted, and on first going round Messrs. Lever Bros., he was very much struck with the variety and number of the notices exhibited. At the same time it was impressed upon him that the question had to be handled with some care. It seemed to him that the matter of notices and such like could be overdone, and the people would get so accustomed to having things done for them that they would grow careless and the thing would lose its effect. With regard to the particular notices contained in the paper they might be suitable in some and unsuitable in other cases. The success of the whole thing lay in getting the interest of the workpeople. Where people had to be supervised to see they carried out the instructions, the question arose, who was going to supervise them? The foreman

Mr. Daniels

Mr. Daniels in a large works had quite enough to do without acting as nursemaid to his people, and if they introduced another official they had to be careful not to introduce friction between the foreman and the official. The same thing applied to suggestions; the success lay in getting the interest of the people. That depended upon how they rewarded them. It had been suggested that a good plan was giving them a year's saving brought about by that particular suggestion. The point would arise as to who would assess the value of the suggestion, and as in many cases the assessment must necessarily be entirely in the hands of the management, it was quite easy to see that some workers who put forward suggestions would think they had not got enough for them. In that way suspicion might enter into the works and cause a great deal of trouble. He thought that all of them must be in sympathy with the general movement, and it was only a question as to the extent and best methods of applying it to particular cases.

Mr. Rettie Mr. C. RETTIE stated that during the last five years he had been connected with one of the largest firms in the country and had witnessed a number of accidents, and it was very difficult to know, in many cases, just exactly what to do. He knew a young engineer who stepped back off a platform that was not finished and slid down the eccentric rods and was killed. In this case it was on a new ship and no blame attached to the firm, the accident happened first thing in the morning and brought out one of the points as regards the time at which accidents generally happened, which had been mentioned by the author, and that was first thing in the morning, when the men were not properly awake, or at night when they were tired. He thought that there ought to be a penalty imposed on men who tampered with machinery that they had no business with. He, personally, had met with a serious accident through the same thing. There were a lot of things that he would like to mention. For instance, when a man was working above a certain height he was supposed to have two planks, but it was not always convenient to get these planks and there was always a temptation to use a single plank. Yet he believed that there was a law that if the man did not get the second plank and there was an accident he did not get compensation. That, of course, rested with the man, and the firm was not to blame for it. He had seen drillers refuse to work until the men came to fix the staging, and he thought that was the proper attitude.

The President The PRESIDENT remarked that, at the commencement of his paper, the author stated: "The question of prevention of accidents in the "workshops of Britain is at present absorbing the attention of employers

“in the mass.” He thought that was a somewhat strong expression of opinion. As far as he knew, the employers were devoting more attention at the moment to dodging the E.P.D. rather than to considering these questions. Again, on page 23, the author said : “ Into all factories “should be introduced Safety Committees, which should be made up of “a number of employee representatives together with an equal number “of responsible persons representing the firm.” He thought the sentiment there expressed was excellent, but as one having some little experience in these matters, he would like to ask the author where these extra duties of employers were going to end. At present, affairs had got into such a condition that, what with Whitley Councils and other organisations, that sat all days of the week, Works Committees and Safety Committees, really no time was left for an employer to get on with his business. Seriously, it meant that their concerns would soon require an additional class of officials, in addition to their managers and engineers, who would have to look after wages and working conditions. He was very interested to hear Mr. Hamilton Gibson's and Mr. Brodie's ideas after the author's, and although they seemed rather divergent he believed they were both right. The author was dealing with large modern factories where almost wholly repetition work was carried out, and where they had thousands of employees, the majority of whom were absolutely unskilled. A very large proportion of the workers were girls, who had to attend to particular processes with machines that did not want any special training or power. On the other hand, many of them had to deal with large engineering works, which was a different proposition. An engineer did not usually take on a man who was quite without skill, even a navvy on a large civil engineering work was a skilled labourer. Such a workman knew his way about, and he did not think it was necessary to appeal to him in the same way as in the case of girls or youths in the repetition factory. There was a great difference between the large engineering works and the modern factory. There was no doubt that even on the important engineering undertakings there was room for something to be done, but it would have to be done in a different manner to that advocated by the author.

The President

The AUTHOR, in reply, said that the principal items brought into the discussion were, the question of notices, Safety Committees, and the methods of drawing suggestions. Now as to the notices, the style of such would naturally be drawn up and adapted to the requirements of the establishment for which they were intended. It went without saying that even in civil engineering, workmen engaged building a

The Author

The Author dam, dock wall, or railway, had every right to feel safe in the execution of their work, apart from the consideration that the employer was under a legal obligation to compensate the victim of an accident : he thought that there was also a great obligation on the employer to see that every reasonable precaution was taken and everything done for the safety and welfare of his workpeople.

He had had considerable experience in civil engineering work, such as the building of railways and docks in his early days, and had witnessed many accidents in connection with both steam navvies and grabs and cranes of every description, and he must say that in many instances, had they been properly guarded, the probabilities were that the accident would not have occurred.

Were they to think for one moment that little or no heed should be taken of a workman simply because he might sustain a scratch or lose the tip of a finger, such injury, lacking prompt attention, might turn out serious and result in the loss of an arm. He thought that every workman had a right to feel safe and to that end careful supervision should be maintained, he should get every encouragement and support from his employer, whereby he would be enabled to work with greater safety and prove more efficient ; in addition, it would be conducive to increased production.

Where a man did not feel safe in whatever work engaged upon, he could not be comfortable, his heart could not be in his work and he did not work with the same confidence.

With regard to encouraging suggestions, he had known splendid suggestions to have been given to his father when he was railway contracting, building bridges and such like. As there were no suggestion boxes in those days it was unlikely such suggestions were submitted in writing, yet even then the results were more satisfactory than they were now on similar work. The wages paid to the workman of that period were not to be compared with the standard obtaining to-day, but he guaranteed that the amount of work done was better in proportion than it was to-day.

They found that where suggestion boxes had been given a trial they had proved a success in so far as eliciting new ideas for the improvement of machinery and increasing of production.

It had been found that workers had failed to put in suggestions for the simple reason that they would have to apply to the foreman or supervisor for the necessary form ; this betrayed an element of suspicion and jealousy which he was sorry to say did exist, and the workman felt that in making the suggestion he might look too efficient

in the eyes of the foreman, who in his turn would be fearful of being superseded in his job. The Author

As regards the notices, they must be drawn up to attract the class of worker they were intended to influence. The specimens they had seen reproduced were not American, and he had not come across one which suggested "the machine was always ready to bite you," unless the machine was insufficiently guarded. It did not follow that because a machine had a guard rail round it that it was sufficiently guarded. They might have a guard rail round which would prevent the workman from tampering with the machinery, but if the workman got inside the barrier he was in serious danger of being nipped.

He quite agreed with the President's remarks with regard to the amount of work involved in the formation of Committees, but it did not mean they should have an independent Committee which would sit on every trivial accident. Supposing that they had an accident with no injury to the workman but serious damage to the machinery through carelessness, an inquiry was held and all the men involved were brought forward and shown how the accident occurred and how to avoid it, thus valuable time would be saved to the firm, greater safety would be given to the workman, and increased production would result.

He must admit that the question of these "Accident Committees" did not necessitate an independent Committee; it did not mean they were going to have the Managing Director and General Manager sitting on the Committee to investigate an accident: if they wanted to encourage enthusiasm in their workmen, let them make the position safe for them. Accidents of a serious nature disorganized the whole of a department for the remainder of the day. If workmen were unnerved, there was no getting away from it, efficiency was reduced, and it was brought home to the employer that he was the loser.

There was the question referred to by Mr. Brodie of the 70 per cent. of accidents due to the human element, and he was perfectly right. The number of accidents reported might certainly be reduced provided they had the necessary appliances handy. The latest regulation of the Home Office was that they must have antiseptic or sterilized dressings. These were specially prepared and made up in different sizes to meet the requirements of the injury, from the tip of the finger to the thigh. He thought that it would be insisted on that every factory should be obliged to use sterilized dressings for all cases of accident.

The Author A very large number of accidents were not reported at the time of occurrence and were not attended to, the consequence was that septic poisoning supervened, there was a tendency to omit reporting unless surgical treatment was imperative, nevertheless there was no shyness in claiming compensation for lost time even though traceable to such omission.

1st December, 1920.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,
President, in the Chair.

The Council reported that the following elections had been made :—
CHARLES RICHARD BOLTON, B. Eng. (*L'pool*), as a *Member*; WILLIAM
HERBERT GREGSON, ERNEST JAMES HAINING, GEOFFREY WILLIAM PARKIN,
DANIEL BLUNDELL PARSONS, and ARTHUR ROUSE, as *Students*.

“Design and Construction of Large Commercial Fuel Oil Depôts.”

BY G. KENYON BELL, Assoc. M. Inst. C.E.

INTRODUCTION.

THE method of dealing with fuel oil imported into this country is very much the same at all ports. The oil in bulk is brought over from the producing country in specially constructed tank steamers, and on arrival at her destination the ship is berthed alongside a quay or jetty specially prepared for the reception of oil, in that there are lines of pipes laid along the quay.

These pipes, which are usually of from 8 inches to 12 inches diameter, have tees fitted with screw-down valves at distances convenient for the average ships which will use the berth. Connection is made between the pipe system on the ship and these tees on the quay by means of flexible armoured hose pipe.

Once connected up, the oil is pumped from the ship's hold to the storage depôt, and if the head be not too great, the ship's pumps force the oil right into the tanks of the depôt. If the head be greater than the ship's pumps can manage, the oil is either pumped into a “half-way house” by the ship's pumps and from there to the tanks by the oil depôt pumps, or the oil depôt pumps are employed direct as a boosting agency to help to overcome the head.

The whole operation of taking in oil to the depôt or discharging it from the depôt to a ship, can conveniently be controlled from the depôt itself by a telephone system which links up the tanks with the office and thence to the quay side.

All the oil in the storage tanks is immediately available for issue to a ship for bunkering, or very often it is fed from the dépôt to an oil barge and in it conveyed to the ship it is desired to bunker. Where possible the operation of discharging from the tanks to the quay is done by gravity, but generally it is found that unless the pipe line be short the viscosity of the oil necessitates the assistance of the dépôt's pumps.

In general, the pipe system is in duplicate, but inter-connected so that the operation of discharging and filling can be carried on at the same time, or if necessary both pipes may be used for the one operation.

CHOICE OF SITE.

In the choice of a satisfactory site for the dépôt it is essential that as much data as possible should be collected about the soil and sub-soil. In this country, as a general rule, it is not possible to select an ideal site, the dock system is generally already in being and the dépôt has to be situated within as short a distance as possible, usually on a piece of waste land or a stretch of beach which may possibly be inundated at half-tide, anything in fact which has been left over from past improvements, and which it is not considered will be required for dock development.

It is desirable that the sub-soil be of not too porous a nature, otherwise in the case of a bad leak it will tend to become oil logged and may possibly be a danger in case of fire. It is hard to say what is an ideal foundation ; whereas it would appear that rock would be the best, still, on investigation, it may be found that the expense of levelling the rock would, in these days of expensive labour, run up the cost unnecessarily.

When considering the suitability of a site it must be borne in mind that for tanks which are to be above ground the whole area of the tanks themselves must usually be enclosed by firewalls, which the local authorities may demand to be of sufficient height to contain the whole of the contents of the tanks, and that they will probably prohibit the tanks being less than 50 feet from each other in the clear.

This must all be added to the area taken up by the selected type of tank, so that even a small dépôt requires a fair amount of room.

From the firewall point of view, a saucer shaped depression is the most satisfactory, as that means that the maximum amount of oil can be contained with a minimum wall, and this will be still further reduced if the earth (if an earth wall be used) is borrowed either

from the tank foundations, thus sinking them somewhat, or from borrow pits within the walls.

Against this is the difficulty of draining rain water, so that it is better to select a site, which if possible is a compromise, having enough slope to make surface drainage simple without being so steep that the firewalls at one part are nil and at another part are exceedingly high.

Another advantage of a site with a slope is that the entrance road can come in where the walls are lowest, and so it will not be necessary to have a steep incline or a bad turn in it, as the road will naturally have to go over the top of the wall. The road to the pumping station and offices can with advantage go around the depôt outside the firewalls, and for general ease in the construction of the depôt, it is advisable that the location of these roads be decided first thing, and that they be put in hand coincident with the beginning of the work on the site.

Having then chosen a site with a suitable soil, it is necessary to know what the underlying strata are, as a sub-soil of clay on a rock which dips steeply is always liable to slide under increased pressure. A peat sub-soil also requires special treatment, or the tanks may settle when full, and in settling could very possibly take a cant to one side or the other.

An example of a very bad foundation is that at Avonmouth, where the tanks are founded about three feet above extreme high water level. The site is all made ground, formed by pumping the spoil out of the Royal Edward Dock and then dumping cinders on top of it, so that the strata is roughly cinders two feet, silt five feet and then gravel.

Communication with the site is required by road, rail and water ; as the depôt would be primarily intended for water-borne traffic, the latter condition would naturally be fulfilled and very probably rail and road communication would be near enough to necessitate only a short connecting piece. In addition, water and electric light from the town supply will have to be laid on, both of which will probably present no difficulty, if the depôt is in a well developed area of the town. If, however, the depôt, as is sometimes the case, be placed on an isolated flat at some distance from the town supply, it will probably be preferable to arrange for a self-contained lighting system. Water will probably have to be laid on, as in very few places is it economical to put down a well or boring, especially for a station such as this, where the nominal supply may have to be augmented in order to deal with a fire, as, although water is not good as an extinguishing agent for an oil

fire, still it might be very necessary to play on any buildings, &c., in the station to prevent them being set alight.

TYPES OF STORAGE ACCOMMODATION.

The types of storage accommodation may be divided into two main groups, below ground, such as the reservoirs in certain parts of Canada, used for crude oil, which are excavated out of the ground, the walls being lined with timber and the bottom being puddled with clay. The second group, and by far the most common, provides for storage above ground in reservoirs of steel or concrete.

At many places, notably at Rosyth, large reinforced and mass concrete reservoirs have been erected, it having been proved by various experiments that mineral oil has very little if any deleterious effect on a good concrete. Twelve years ago, reinforced concrete oil reservoirs were in use in California, there being one of 1,000,000 barrels capacity at Richmond. They were usually constructed about one-third below ground and two-thirds above ground, the excavated earth being used for the walls. The whole was then lined with concrete. Two reinforced concrete tanks built at San Luis, Obispo, California, in 1911, were 601 feet inside diameter by 20 feet $4\frac{1}{2}$ inches high, each with a capacity of 1,000,000 barrels.

A more recent example, that of Rosyth, was described in "The Engineer" last year. These tanks were designed for a combined capacity of 60,000,000 gallons and were built partly in mass concrete and partly in reinforced concrete. The utmost care was taken to lay the concrete so that there might be a minimum of cracks, but despite all this it was found necessary to cover the floor with 6 inches of concrete having two layers of expanded metal in it. The mix of this further layer was $2\frac{1}{2} : 1\frac{1}{2} : 1$, other mixes being $7 : 3 : 1$, the stone being broken to pass through a 2-inch ring for "mass" work and the fine concrete for facing was composed of a mix of $3 : 1\frac{1}{2} : 1$, the stone being broken to pass through a $\frac{1}{2}$ -inch ring.

The more usual form of container is a cylindrical steel tank, which may be obtained in various standard sizes, of which the 2,000,000-gallon size is probably the most suitable; in this instance a typical example of this size of tank is 114 feet 6 inches diameter by 32 feet high, with a bottom plate of $\frac{1}{4}$ -inch, the first or lowest course of wall plates being $\frac{5}{8}$ -inch; a somewhat heavier type, having the same capacity, is 112 feet diameter by 32 feet 9 inches high and having $\frac{3}{4}$ -inch bottom plates and $1\frac{1}{8}$ -inch plates for the first course. In both cases, the roof, which is of the lightest possible construction, is supported from a central tower.

A great advantage of the steel tanks, is that they take up very little room in comparison to the amount of oil they contain, and in the case of a fire, it is very seldom that a whole tank collapses, one or two of the top rings, of course, may be badly buckled by the heat before the oil can be drawn off, and may require renewing, but not the whole structure, and the work of patching up is a more or less straightforward job, the tank afterwards being very little worse than before the fire.

One advantage of the concrete tanks is that the oil contained will not be affected to a very great extent by atmospheric temperature fluctuations, so that the amount of steam heating required will remain fairly constant during any one season of the year.

Figs. 1, 2 and 3, show tanks in various stages of erection.

Fig. 1 shows a tank bottom partially constructed on trestles preparatory to having the first ring built, while in Fig. 2, the tank in the foreground has the first ring completed and is ready to be lowered. The tank in the right background has five rings completed and that in the left background has all the rings finished and the roof is being put on.

Fig. 3 shows a nearer view of a completed tank.



FIG. 1.



FIG. 2.



FIG. 3.

LAYOUT.

Assuming, for an example, that it has been decided that a new depôt will have to be protected by a firewall system, which will enclose 75 per cent. of the contents of the tanks, there are two broad principles which will govern the layout, either it will be a multiple or a unit system. The multiple system consists of one firewall encircling the whole tank area, and with the height of the wall sufficient to contain 75 per cent. of the contents of all the tanks. In addition to this surrounding wall, there would be lesser or splash walls around each tank. The object of these splash walls, which would be only three or four feet high, would be to localize a bad leak, or in the case of a fire to prevent a sudden rush of oil if a course were to collapse, so that the height and perimeter of the splash wall may be governed by the amount of oil which would be discharged if a ring of the tank were to collapse, allowing a little extra for the flowing effect of the oil upon reaching it. The contents of a full course, in a tank of this size, would be about 330,000 gallons in the case of a six-course tank, but the ring would be very unlikely to collapse until, at any rate, more than half of the oil in it had been burnt. Figs. 4 and 5 show a typical example of a depôt laid out on the multiple system.

The unit system would provide a wall around each tank sufficient to take either the whole contents or a proportion, such as 75 per cent. of the total contents of it; in this case there would be no splash walls.

The unit system, in the case of a fire, might serve to localize the effect of the fire, and the oil be drawn off from the blazing tank to another empty one, whereas in the multiple system if the tank were fairly full and collapsed, overflowing the level of the splash walls—a doubtful contingency—the whole area might soon be ablaze, but against this latter danger, it must be remembered that fuel oil has a comparatively high flash point and is in consequence very hard to set alight when protected by the tank walls from the direct action of the flames.

Cases have occurred where the tanks have stood burning without collapsing, and in the majority of cases it only means that one or two rings are destroyed by the heat of the flames from the oil burning in the rings below them, so that the danger of a sudden influx of blazing oil is not very present.

A disadvantage of the unit system, is that it cuts a station up badly, and if concrete firewalls are ruled out, as being unsuitable, and earth used instead, it takes up more area besides being more costly to construct, drain and maintain, and in view of the above the author is of the opinion that individual firewalls are a somewhat unnecessary

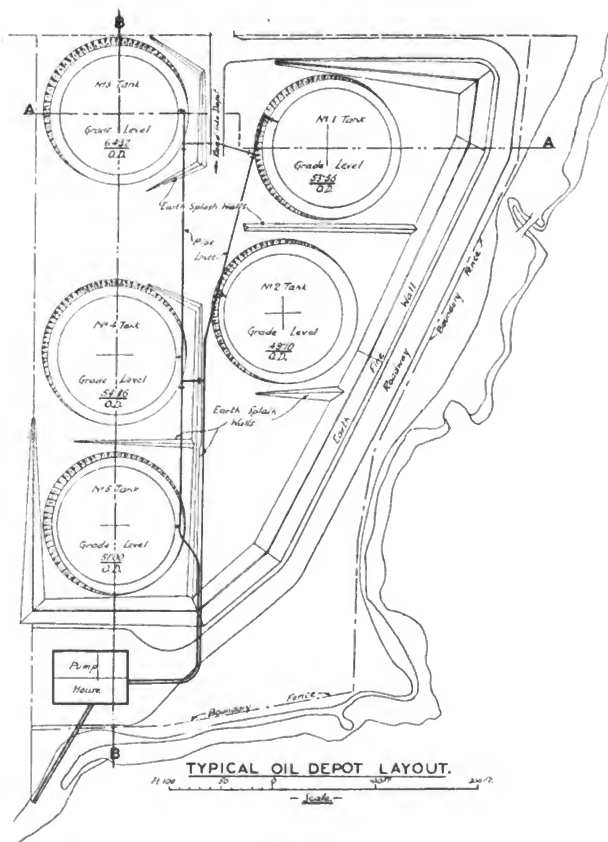


FIG. 4.

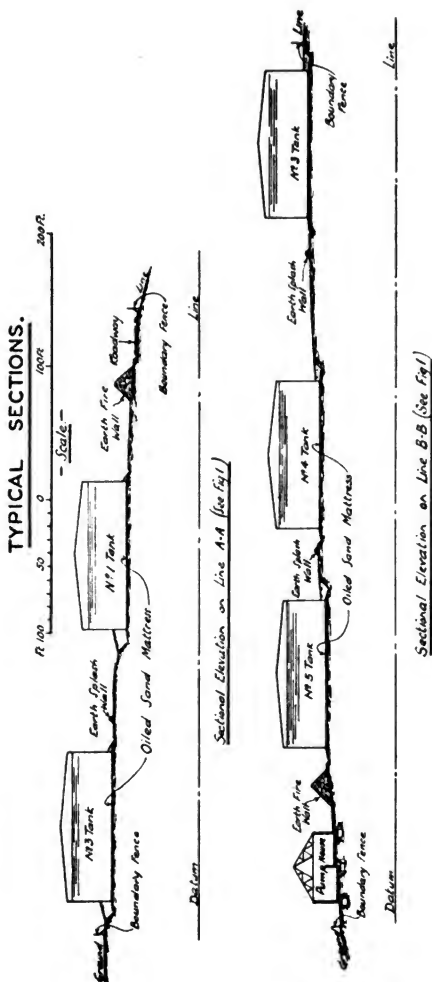


FIG. 5.

requirement for heavy fuel oils, especially when it is realized that the object of the local authority in ordering firewalls is not the altruistic one of protecting the oil company's station, but rather of taking all precautions that none of their own or dependent property is harmed.

In every case it is advisable that the pumping station should be placed outside the firewalls and, if possible, at such a distance that it is reasonably safe from a fire within the dépôt.

FIRE PROTECTION.

In designing the firewalls, concrete or masonry should only be used if they are sheathed in earth, turf or soft rock to protect them from the heat of the flames, otherwise they will spawl and very probably fail, in which case they are useless. The concrete then would just serve the purpose of a core, so that clay would serve the same purpose and is generally cheaper.

There is not the same pressure or the same danger of seeping through in heavy oil as in water, so that a somewhat lighter section of wall may be used. The walls may be constructed, if of good compact soil and well turfed, with a slope of 1 : 1 up to a height of about 20 feet, and it is possible to get such slopes to stand without turfing until grassed if due precautions are taken; beyond this height it is probably preferable to ease the slope. In both cases the top will have to be rounded off and should be well turfed, not grassed, so that there is no danger of rain water standing and soaking down. The clay core, the thickness of which depends on the quality of the clay and the height of the wall, should be well puddled, but need not be worked to the same extent as in earthen dams for waterworks, and ought to be carried well below the ground surface, depending on the porosity of the surface soil. If it is at all practicable without undue expense, it is desirable to carry the clay core down to an impervious stratum. Splash walls which may be used to localize leaks, &c., in a multiple system, can be of the same form as the firewalls, though only three or four feet high, but need not be constructed with a clay core.

In the case of both fire and splash walls, where the soil is of a light sandy nature, it will generally be advisable to ease the side slopes.

The design of the earth firewalls against the liquid pressure of the oil will be treated generally in the same way as in any other form of earthen dam.

In some cases oil depôts have been placed on strips of the fore-shore which are bare at certain states of the tide. In this case the encircling protection embankment will have to be designed to with-

stand the liquid pressure of the water at extreme high-water and also any wave effect or scouring action which might possibly come upon it, which may make a wall considerably heavier than would be required for oil alone. Here the determining factor of the dimensions of the wall will be either the force due to the height of water or possible wave stroke, or the quantity of the oil to be retained, whichever is the greater, since the embankment will also serve as the firewall to the station.

In the case of a station such as the above, where at certain stages of the tide it is impossible to run off the surface drainage, it may be necessary to run all the surface water to a sump, from which it can be pumped over the wall when the water outside is at too high a level to permit of drainage by gravity.

DRAINAGE.

The station must be well drained, so that after heavy or continued rainfall the water does not lie about in pools or flood low-lying portions, and in order to carry all water clear of the tanks themselves, it is desirable to concrete or pave a width of at least five feet all round them, with a slope of, say, 3 inches from the tanks to an open drain.

This open drain is led into an oil trap on the inside of the splash or individual firewalls, out of which it is led in a pipe through the splash wall and connects up with the main drainage system of the station, which may be piped or open ditch.

The main drain in its turn is led to another oil trap, from which it passes through the outer firewall in a pipe, and is so discharged on to the foreshore.

The idea of the oil trap, is so that all oil from leaks, which may be carried into the drainage ditches by the surface water, may be trapped and prevented from being discharged out of the main pipe outside the depôt, where it may easily develop into a dangerous nuisance.

All drain pipes where they go through splash or firewalls, should be flanged in one or two places, so as to prevent oil or water creeping alongside them, the trench through which the pipes are led under the walls being well tamped with puddled clay all around the pipes. In the case of pipes going through or under the main firewall, one of the flanges ought to be situated in the clay core. All drainage pipes must have screw-down valves outside of the fire or splash walls which they serve, so that in the case of a fire or leak a man can go along outside the compartment affected and close them down. It is advisable in the case of the firewalls to have the valves outside rather than in the centre of the walls, with the valve spindle led up to the surface,

on account of initial and maintenance expenses, and also because in the case of a fire, the firewall may blanket the man to some extent from the effects of the flame and smoke. In order to assist surface water to run off and to keep the dépôt fairly dry, it is desirable to cover all the earth portions with well rolled cinders or gravel.

FIRE-FIGHTING APPLIANCES.

Fire-fighting appliances for oil would have to consist of some chemical composition, as water would, in general, only make matters worse. Various experiments with an inert gas have been tried and proved successful, one in Hamburg, in 1911, consisted of equal quantities of caustic soda and alum solutions, which yielded about seven times its quantity of a yellow-white foam, which could be pumped through a pipe like water.

A carbonic acid gas foam, which has been used with considerable success in big dépôt fires in the States, is now on the market, and was described in "The Engineer" last year.

Lightning conductors are not now considered necessary, at any rate in this country, as the risk of fire due to lightning is very remote indeed.

FOUNDATIONS.

The question of the foundation necessary for these big tanks, on a normal soil, is not a very difficult one, as the pressure per square foot for the oil alone, ranging from a normal 50,000-gallon to a 2,000,000-gallon tank, is approximately 8 cwt. per square foot for the smaller tank, gradually rising to 17 cwt. per square foot for the larger one, which is not large, so that the chief danger to guard against is tilting or buckling of the tank, due to the uneven quality of the material that it is founded upon.

On rocky ground the only work necessary is to level off the rock very carefully, taking care that the surface, before the reception of the tank, is free from any pinnacles or small boulders which might pierce the bottom, which being only about $\frac{1}{4}$ -inch thick is liable to be damaged.

Where, owing to a fault or some other rock formation, a portion of the tank would be on rock and the remainder on a rather compressible foundation, the rock may be cleaned up over the whole surface, and the low portion made up with concrete or rock grouted with concrete. In one case, in order to lessen cost, the author's firm arranged that a small

depth of the rock area should be excavated below finished grade, and when so excavated should be filled in with moist, well rammed clay, so that there was a good compressible cushion between the rock and the bottom of the tank, with a result that when the latter was filled, settlement would take place equally all over the foundation. Of course, if the rock finishes off in marsh or peat, or any other bad foundation, special treatment will be required, and the foregoing suggestion will not be applicable, and very probably it will be necessary to clean out all the bad ground down to the rock level and make good with stone grouted up with concrete. On marshy ground, mattresses of brushwood, or of creosoted logs, have been tried with success, as have also piles, which latter, of course, are expensive. A mattress of reinforced concrete would carry the weight all right, but against this is the fact that any heavy foundation, such as concrete or reinforced concrete of sufficient strength to stand over a bad foundation, must be added to the total load per square foot to be borne by the ground.

At Avonmouth, a mattress of ballast carefully packed on top of the cinder surface has been used in some instances, but many of the tanks have settled and are well out of plumb.

In the newer depôts reinforced concrete platforms are being put in, but the tanks have not been tested yet, so that it is hard to say whether they will be any improvement.

When it comes to ordinary good earth or clay, matters are much simplified. One type of foundation is made by levelling off the ground and then finishing off with carefully packed ballast to a depth of, say, 9 inches, on top of which are spread chippings broken to go through a $\frac{1}{2}$ -inch ring, to a depth of another 2 inches, but with good earth this is not necessary. In the latter case it is sufficient to level the earth off and then spread over it from 3 to 6 inches of carefully selected sand, free from stones and any salt or other impurities likely to cause corrosion of the steel bottom; thus clean surface sand from an estuary would be ruled out on account of the salt. The sand is then saturated to a depth of at least 1 inch with crude oil, remembering that the oil must be poured on in a fine film so as not to disturb the levelled surface of the sand, and that the sand must be as dry as possible, in order that there may be good cohesion between its particles and the oil. When it is considered that enough oil has soaked in, the tank bottom and the first ring may be gently lowered down, after which the building of the remainder of the tank may proceed. Concrete and reinforced concrete bases have been used in a good soil foundation, but oiled sand, provided the work is carefully done, appears to fulfil every require-

ment necessary, and it has the advantage that it is infinitely cheaper. In neither case can the bottom of the tank be examined from the underneath.

PIPE LINE SYSTEM.

The tanks when in position are connected with the pumping station and thence to the quay by a system of pipes, which will vary in size according to the magnitude of the dépôt and the capacity of the pumps. An ideal system is to have a dual pipe line running up the middle of the dépôt, with the various tank connections running off it, and this main system so inter-connected that any tank can be filled or emptied from either pipe, that oil can be drawn off from one tank to another, and that one tank can be filled while another is being emptied.

Most of this can be arranged without a very intricate system of valves, which last point, in design, must not be overlooked, as the ideal system is simple and one that can be explained to a valve man in a few minutes, and in this connection it must be remembered that every inter-connection requires three valves, and every valve means additional complications in the steam pipe system, if it is found necessary to heat the oil within the pipes in the station itself.

Heavy fuel oil requires its temperature to be raised in order to make it flow readily through the pipes, and this is effected by means of steam pipes which are inserted through the walls of the tanks and branch out into coils of radiating capacity sufficient to keep a large bulk of the oil, especially around the outlet pipe, at a temperature high enough to make flow through the pipes easy.

The viscosity of all crude oils is practically constant at 200 degrees Fahr., and at this temperature is almost double that of water, this fact affects the pipe line layout, in that right angle or sharp bends very soon affect the efficiency, so that a system which is a mass of sharp turns will very soon reduce the output of the pumps.

In most cases the oil, if kept at a temperature of from 90 to 100 degrees Fahr., will flow readily through the pipes, and this is usually about the working temperature.

Often the heat supplied in the tank is considered sufficient to carry the oil to the pumps, so that no heating is necessary up to the pumping station, which simplifies the station pipe layout enormously, as, if internal steam heating be used, every valve system in the main line means a stuffing box on each side, in order to allow the steam pipes to come out. The valves to the individual tanks being on the connections off the main line, do not affect the steam pipes. Beyond the pumping

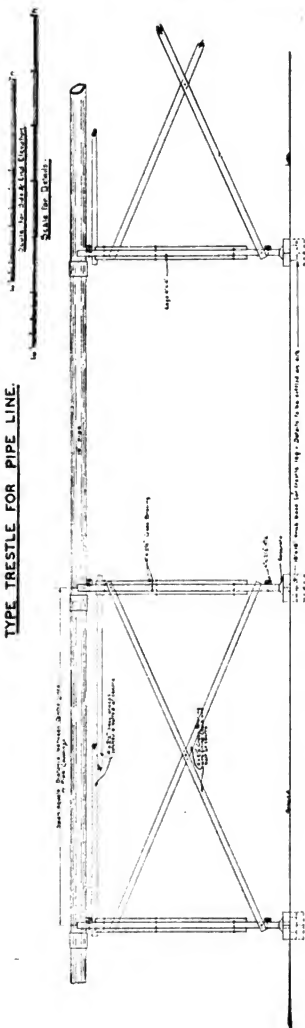
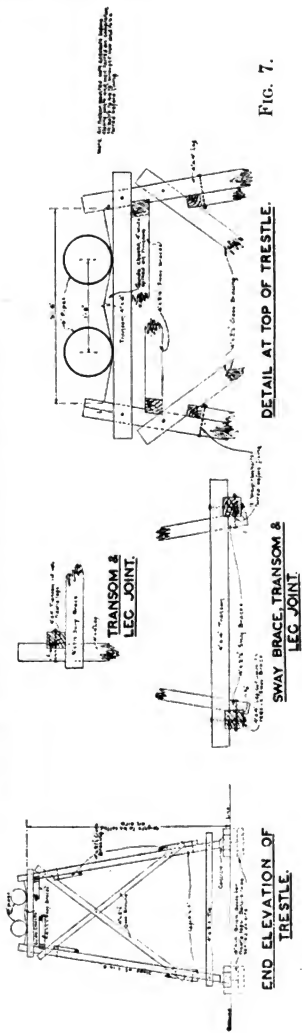
station to the quay it is generally considered necessary to heat the oil, in this country at any rate, where the sun temperature is not very high. If the pipe line be run through a culvert, this is a very simple operation, as the steam pipes can be laid between the two main oil pipes and will keep the temperature fairly even.

If the main is trestled, or in cut and cover, and is not run through a culvert, the operation becomes much more intricate, as the steam pipes will have to go inside the main pipes and must be led out through stuffing boxes at each bend or expansion joint, and in long lines of tangent, means will have to be provided whereby the steam pipes can be drawn out in order to remedy any defect which may occur, all of which complicates the system and provides another weak link.

From the pumping station to the quay an ideal pipe line would be laid with a self-draining slope to a sump, so that at the conclusion of a day's pumping any oil remaining in the pipe would drain to the sump and from there be forced by a pump to a small tank of ample capacity to take the contents of the lines. This tank could be used to supply small quantities of oil when it was not considered desirable to issue from the main depôt.



FIG. 6.

TYPE TRESTLE FOR PIPE LINE.SIDE ELEVATION SHOWING TRESTLES BRACED IN PAIRS.FIG. 7.

Generally the type of pipe used is a mild steel or wrought iron pipe with screwed ends, though cast iron ones have been used in Rosyth and other stations. Ordinary sleeve couplings are used on most of the joints, but in the larger pipes screwed flange joints are used on making-up pieces and when connecting to tees and valves.

Where the pipe line passes over a dip it will generally be found convenient to carry it on a light trestle, of which an example is the temporary timber one shown in Figs. 6 and 7. At any sharp bends a form of thrust block similar to those constructed on water pumping mains will have to be put in.

It has not been possible within the scope of the paper to go into much detail, or to deal with the design of pumping stations or long distance pipe lines for the transmission of oil. But in connection with the latter it should be noted that the method of conveying fuel oil from source to port of shipment by long distance pumping, which has so long been the practice abroad, particularly in the U.S.A., has now become a business proposition for dealing with oil imported into this country and the continent, as evidenced by the Havre-Paris oil pipe line, and the Glasgow and Rosyth line.

In conclusion, the author wishes to express his indebtedness to Mr. A. Carrick Smith, Chief Engineer of the British Mexican Petroleum Company, Limited, for permission to visit stations and to reproduce plans and photographs, and also to Mr. B. O. Warren, Superintendent at the Liverpool Depôt, and to other Superintendents of the Company for much kindness and valuable information.

The Paper was accompanied by plans and photographs which have been reproduced in the text.

DISCUSSION.

The President

The PRESIDENT remarked that the author had presented a very interesting paper on an up-to-date subject. It was said that the present age was the oil age, and he was of the opinion that the members present had been afforded an opportunity of learning something about a subject which was certain to become much more important in the future. Liverpool, particularly, should be interested in view of the development now taking place at the south end of the dock estate, which was bringing a new industry into the city. It was of the very greatest importance. He was sure that they would wish to give the author a very hearty vote of thanks for his interesting and valuable paper.

Prof. Watkinson

Professor W. H. WATKINSON felt that he had nothing to contribute towards the discussion but he would like to ask a few questions. One was as to the velocity of oil which might be allowed through the pipe. Another was the head required for, say, a 100-foot length of pipe, when forcing the oil at the standard velocity; and thirdly, what was the kind of pump used, the reciprocating or the centrifugal type? He had often wondered, since he had seen those tanks erected at the south end of Liverpool, why such valuable land should be used for that purpose. If oil could be, and it was, sent through pipe lines 1,000 miles long, surely the tanks might have been put in the country, several miles from Liverpool, where the land was cheap. A little extra cost would have been involved in pumping, but that would not have been appreciable. They might have seen the last war, but they might not, and conspicuous tanks near the river were very vulnerable to attack by aeroplanes. To minimise such danger the tanks should have been put inland and sunk below the level of the ground so as to be invisible. Presumably there were good reasons why such obvious precautions had not been taken. He had enjoyed listening to the author's paper, and he was sure it was a very valuable contribution to their "Transactions."

Mr. Ellis

MR. SOMERS H. ELLIS said that he attended the Meeting chiefly with a desire for information, a desire which had been abundantly gratified by hearing the author's very informing paper. There were, however, one or two points about which he should be glad to have further information, and chiefly one referring to the heating of the oil.

It was rather a difficult question, particularly when ships had to be considered, but in the case of tanks it seemed to have been grappled with successfully. He would like to know how the heating coils were arranged. Were they placed in a horizontal position close to the bottom of the tank, or was it necessary to carry them higher up? The author spoke of putting a coil round the outlet, but considering that heavy oil, such as that from Mexico, was solid at a temperature of about 35 degrees Fahrenheit, it seemed to Mr. Ellis that to heat only the space immediately round the outlet would leave a solid column of oil farther away, under certain conditions, and that proper flow would not take place. Mr. Ellis

He had visited the large oil installation at Thameshaven last year, and saw there a scheme for distributing oil to the various tanks, by which complicated valves were eliminated. Each group of tanks had a central pump-house, connected by pipes with each tank in the group, with every other pump-house, and with the pipes on the wharves. The pipes had open junction ends where they entered the house, and were connected with the pumps or with each other by means of removable flexible hose-pipes, coupled on to any junctions (by hand) at will. This system, by which any tank could be connected to the ship or to any other tank, was a little more cumbersome than one depending on valves, but for a large installation seemed to have many advantages.

The Thameshaven installation was situated on the Thames marshes, soft ground covered with grass, and all fairly level and homogeneous in character. In forming the foundations for the tanks they were careful not to remove the turf, but deposited on top of this a layer of broken chalk, about 18 inches in depth, and finely crushed for the top inch or two, which was levelled for the reception of the tank bottom. Except in the case of one tank, they did not appear to have had any unequal settlement, and the scheme evidently answered very well. The author had said that when tanks were being built, they were first of all erected on trestles, and afterwards lowered on to the foundation when the bottom ring of the sides had been riveted in place. Was this so that the bottom might be tested by water before placing on its permanent bed?

He felt that they were greatly indebted to the author for the valuable information which he had given to them.

Mr. R. E. GIBSON wished that the author's paper had been written a few years ago, as at that time he was engaged on the extension of two small oil storage installations. The foundations were entirely different to any of those described by the author. The bottom of the Mr. Gibson

Mr. Gibson tank was placed on a number of walls about five feet apart, running parallel with each other, and about three feet high. On the top of the walls narrow rolled steel joists were placed, upon which the bottom of the steel tank rested. In that way it was not necessary to use trestles during erection and testing, as the tank was built in position on the joists. Moreover, the underside of the tank was accessible throughout for inspection at any time, and for painting, while the plates were kept free from damp as surface water drained away and left the tank dry. That form of foundation was, no doubt, a little more costly but had been proved to be very satisfactory. In regard to pipe lines, the author had made no mention of the use of back pressure valves. In long oil pipe lines, he considered it desirable that holding up valves should be fixed to prevent loss of oil in the event of the pipe bursting. A short time ago an occurrence of that kind took place at Garston. The flexible hose pipe, connecting the ship pump to the pipe line, burst, but a back pressure valve, fixed near the dock quay, held up the oil and prevented loss. The provision of such a valve was well worth while in view of the high prices of oil now prevailing.

Mr. Wall Mr. A. T. WALL remarked that it did certainly seem to be a great disadvantage that they were not able to examine the bottom of the tank, when built in the way described in the paper. He would like to know how the outside of the tank should be treated from a preserving point of view. He would also like to know what allowance was made for expansion in the tanks generally; five per cent. was talked of in ships, although it was not followed by any means, only in the Admiralty service, where it was particularly so. With regard to the heating of the oil and the rise in the temperature, this was tested in a warship afloat. It was found that the rise was only a few degrees, but the oil was made viscous enough for the pumps. The author did not tell them the test pressure he put on the tanks, it would, perhaps, be interesting to know that. The information in the paper was quite new and very interesting to him personally.

Mr. Needham Mr. C. A. NEEDHAM was glad to see the reference made by the author to the reinforced concrete oil reservoirs and was most interested in his statement that "mineral oil has very little, if any, deleterious "effect on good concrete." Unfortunately that was not his experience, for he found that oil and concrete usually profoundly disagreed, but perhaps it was the word "good" used by the author which made all the difference.

He had read with great interest accounts of the construction of the sixty-million-gallon oil reservoir at Rosyth, and had not yet ceased

wondering, when they came to have to carry out repairs to cracks and other small weaknesses, which were bound to occur from time to time, how they were going to be dealt with.

Mr. Needham

He had found in his experience that concrete, however carefully laid, would persist in developing cracks, due mostly to temperature variations, and that concrete in the neighbourhood of oil usually became thoroughly permeated, and it was then a matter of considerable difficulty to obtain a surface to which any new work could be made to grow.

It would be of considerable interest to him to hear how those large reservoirs behaved in the course of time.

Mr. C. RETTIE raised the question of oil as having a deteriorating effect on rubber in the case of running cables. On the question of heating it struck him that there was a great field for electric heating, although the heating, of course, was much cheaper than electricity, where they had the heat directly applied. Where they had a number of tanks widely scattered there must be a big loss in carrying the steam from point to point. He would like the heating of the tanks explained more for that reason. He would like to know whether the oil congealed very quickly after the heat was applied locally to the oil to make it thin, and to what distance it travelled. It struck him it could not go very far before it congealed again and choked the pumps.

Mr. Rettie

The PRESIDENT thought that there appeared to be a general conspiracy to ask for information from the author and he was going to join in the plot. He was rather envious of the author or any other engineer who had to deal with oil and the flow of oil through pipes and valves, because he had something to do with pipes and valves in connection with water supply, and he could not imagine any greater joy than to have to work with a fluid that caused no corrosion and automatically lubricated the controlling valves. Mr. Needham had raised the question of the concrete flooring of the tank, and it was a subject he would have liked to say something on had there been time to do so. With regard to the cracks referred to by Mr. Needham, he appeared to have encountered the same trouble which most people had experienced in laying large areas of concrete for floors of reservoirs or tanks. He would like the author to explain, if possible, exactly what methods were adopted when he said that "the utmost care was taken to lay the concrete so that there might be a minimum of cracks." Personally, he was satisfied that one could put down the best concrete in the world with the greatest caution and yet get cracks in it. Without putting some form of continuous reinforcement into it they could

The President

The President not prevent concrete expanding or contracting when laid in large areas. A question was asked as to the testing of the tank, whether it was done by compressed air, he thought water was suggested. He was recently reading an account of some experiments and tests made in the United States, where they found that they had a number of failures in steel tanks owing to the joints of the plates loosening. In this case the joints had been made tight with red lead and other material of that nature, which was acted upon very rapidly by the oil, and he believed that there was nothing that would stand except caulking. With regard to the emptying of tanks, he wished to know if air pressure was ever used for that. He presumed in the case of underground tanks, where the roofs were sufficiently strong and airtight, some such system would be employed. Obviously, the oil would have to be thin or be heated so as to flow freely. He also came across some American specifications for oil tanks constructed in concrete, and they required that all concrete that was to come into contact with oil was to be kept clean for six weeks after the concrete was laid, showing that new concrete would not stand the oil before it was matured. He would like to know whether that was so.

Mr. Whitaker Mr. H. A. WHITAKER thought that there was great need for further information on the subject of the author's paper. The author had limited his paper to a discussion on oil depôts, but he had mentioned the problem of the flow of oil in long pipes, and had indicated the difficulty of an economic solution.

Members would probably be interested in the results of some experiments with oil in long pipes, summarised in the "American Civil Engineers' Pocket Book," 3rd Edition, from accounts given in "Engineering News," 3rd June, 1906, and "Engineering Record," 25th May, 1908. If the figures were approximately correct and supported by later experiments, they indicated a way by which great economy in oil transport might be obtained merely by adding about 10 per cent. of water to the oil in the pipes. With plain pipes the oil and the water formed an emulsion from which it was difficult to separate the water; but if rifled pipes were used, the rotation set up caused a thin film of water to form along the perimeter of the tube, and the two liquids separated quite easily on being allowed to stand in a tank.

The article referred to said: "The rifling of an 8-inch line, used by the Southern Pacific Railway Company, consists of six helical grooves in the circumference, making a complete revolution every ten feet of axial length."

The results of tests made by the Southern Pacific Railroad Mr. Whitaker Company gave the following values for K in the formula :—

$$h_f = Kv^2 L/1000 D,$$

where h_f = The frictional loss of head in a length L .

v = Velocity of flow in feet per second.

D = Diameter of pipe in feet.

8-inch plain pipe carrying oil only	...	...	$K = 134$
8-inch plain pipe carrying 90 per cent. oil and 10 per cent. water	...	...	$K = 79$
8-inch rifled pipe carrying 90 per cent. oil and 10 per cent. water	...	...	$K = 0.95$
3-inch plain pipe carrying oil only	...	...	$K = 284$
3-inch rifled pipe carrying 90 per cent. oil and 10 per cent. water	...	...	$K = 0.64$
Mean of above pipes for water only	...	...	$K = 0.35$

The results were so remarkable that one would like some further light on the subject. The experiments were about fourteen years old but he had not been able to find any later results. It would be interesting to have some comparative figures on the flow of oil at different temperatures. He thought it was a matter on which a good deal of research could be carried out in view of the increasing use of oil in this country. If the presence of a small proportion of water was not harmful in fuel oil—a matter for the mechanical engineer to decide—then the addition of a little water in the pipes might do away with the continuous expense of heating and effect a great economy. He noticed in some of the illustrations in the paper that pipes were carried on trestles quite exposed to the atmosphere, and he would like to know whether any trouble had been experienced through loss of heat in the oil. A question he wished to raise was in connection with the cores in the firewalls. Unless these were expected to act as reservoirs, clay cores did not seem necessary, though, of course, every case was different and depended on the nature of the subsoil.

With regard to storage, they were dealing with large quantities of oil and he wondered if the author could give any information as to the economic proportions of tanks, and the limiting ratios of height and diameter. Special considerations might necessitate having a number of small tanks in an installation, such as the ability to clean one tank while the others were kept full, and also as a means of reducing the danger from fire.

Mr. Whitaker

Perhaps some members interested in shipbuilding would be able to supply some information on oil-tight riveting. The President had mentioned the danger of using foreign materials and fillings for caulking the joints in tanks, and everyone would agree with his remarks on the subject. He, personally, had seen some tanks at one of the naval bases on the East Coast which had been splash-painted, and all the painting had been discoloured through oil working through the joints. He did not think that tanks could be tested with compressed air, because that would exert a uniform pressure on the roof and sides, and tanks were designed for a varying pressure and had a very light roof. Water, which was slightly heavier than fuel oil, would be suitable for testing.

The Author

The AUTHOR, in reply, said that in answer to Prof. Watkinson's questions, the allowable velocity of oil through the pipes was complicated by the fact that it was governed by the viscosity of the oil, which altered according to its temperature and also by the size of the pipe. It could be worked out roughly for any known viscosity and temperature and size of pipe, taking water as a base. The viscosity at 200 degrees Fahrenheit of all oils was practically the same, i.e., approximately double that of water. He was not aware of any complete published figures giving the viscosity of oils through different ranges of temperature. In most cases which had come under his notice a reciprocating pump was used; in some cases rotary pumps had been used.

He was afraid that he could not assign any reason for the almost universal habit of oil Companies placing their depôts on most expensive land and in a position where they were open to aeroplane attack, though he knew of one depôt at Southampton, which was about $1\frac{1}{4}$ miles from the water and in almost park-like surroundings hidden amongst the trees. But, at the same time, it must be remembered that oil tanks wherever they were placed, unless they were below ground, would be most difficult to camouflage against aerial attack, as they threw a very sharp shadow.

He was most interested in Mr. Somers Ellis's remarks about the Thameshaven station, and in many cases it appeared to him that it would be advantageous to use the flexible connection system, as it certainly simplified the task of making every tank interchangeable. The foundations at Thameshaven appeared to be similar to certain of the bog railways in Ireland, where it was found that it was fatal to remove the crust of the bog. With regard to Mr. Ellis's further remarks, the steam piping was not taken in a small coil just around

the outlet pipe, it covered quite a large area inside the tank, being especially concentrated just by the outlet (as was stated on page 56). Generally speaking, fuel oil only got more or less solid when it had been left without heat for some time and the heavier constituents had time to settle, when it developed into a rubbery mass at the bottom.

Tanks were built on trestles in order that the bottoms might be riveted up before they were lowered on to the ground. The foundations mentioned by Mr. R. E. Gibson were put in some time ago, when labour and materials were considerably cheaper, and, in this country at any rate, the feasibility of putting the tanks direct on to the ground had not then been seriously entertained. As regards the bottoms deteriorating, the sand was fairly well saturated with oil before the tank bottom was lowered, and there was sure to be a certain amount from the tank which would tend to help things (see page 55). He agreed with Mr. Gibson that in a long pipe line back pressure valves might prove very useful.

With regard to Mr. Wall's questions, tanks were generally coated with paint or a bitumastic solution, of which, probably, the latter was the better. As the tanks were not filled to the brim there was ample room for expansion. Water was generally used to test a tank. It was not possible to use compressed air, as the roofs were of the lightest possible construction, so would not stand the reverse pressure and in addition they were not airtight.

Mr. Needham rather pulled him to pieces about oil on concrete, but he had quoted from a series of tests which had been made in various parts of the world, over a period of from one to two years, and the unanimous result was that mineral oil did not harm good concrete. By good, he presumed a well mixed rich concrete which had had ample time to set, which might, of course, be the solution of Mr. Needham's difficulty. At Rosyth, he understood that the cracks developed during construction, so that they were grouted up before the oil was admitted.

Mr. Rettie's query about the oil damaging the cables, presupposed a badly designed and executed cable line, and ought not to occur in any properly thought out and equipped depôt. It appeared to him that electrical heating of the oil would be immeasurably more expensive than steam. Far from the oil congealing after it left the pumps, it had to be remembered that at the depôt, at Liverpool, with which he had been associated, there was a length of steam pipe running inside the oil pipe line, and the result was that the oil reached the quay at approximately 2 degrees Fahr. higher temperature than it left the pump.

The Author

As explained in the text, the remarks about Rosyth were an excerpt from "The Engineer," but he presumed that the floor was laid in small sections, as otherwise he agreed with the President that they could not expect to get a crackless floor. He apologised for omitting to mention in the paper that in oil tanks all joints must be well caulked; red lead and other fillings would be useless for a lasting job.

He had been very much interested in Mr. Whitaker's quotations from the "American Civil Engineers' Pocket Book," and the results certainly appeared as if rifled pipes and water approached to the millenium. As mentioned in the reply to a previous speaker, there was no drop in the temperature of the oil in the pipe. Regarding the flow of oil in pipes at different temperatures, as there appeared to be a deficiency of reliable information, he suggested that the University might step in and carry out some tests. The demand made in some cases for clay cores in the firewalls was certainly rather stringent, and no doubt very often might be dispensed with.

In conclusion, the author thanked the President and Members for the kind way in which they had received his paper, and hoped that he had managed to present something that was new to them.

CORRESPONDENCE.

Assoc.
Prof. Wilton

Assoc. Professor T. R. WILTON desired to refer to a few of the points which had been dealt with in the paper, more particularly as, being in partnership with the author, he had been associated to some extent with work described in the paper.

It was of interest to note that, so far as he was aware, the system of a submarine pipe line connected by flexible hose with a floating buoy, although it had been adopted abroad in at least one case, had not been used in this country for ships-discharging or loading oil, and doubtless the jetty or quay system was far preferable under the normal conditions prevailing here. The author's remark that it was hard to say what was an ideal foundation, showed how necessary it was to treat each case on its merits, no hard and fast rule could be laid down as to what was the best type of foundation to adopt. The adoption of firewalls as a matter of general practice was certainly most advisable, although, even in this country, there were cases where they had not been provided. In case of a fire occurring and damage being caused

to surrounding property, due to the omission of firewalls, the matter of liability for such damage might well be a very serious one.

Reference had been made to the nature of the foundations near to the Royal Edward Dock. A good many years ago he had the privilege of being shown over this by the Engineer of the Bristol Docks, the late Mr. Squire, who was one of the original members of the Liverpool Engineering Society, and had then heard a good deal about the nature of the material obtained from the docks. It certainly appeared not to be a very desirable type of foundation and probably when settled was much like the material found at the Alexandra Dock, Newport, which partook somewhat of the nature of a very stiff jelly, and on the addition of a little water turned to a kind of viscous fluid.

Referring to Fig. 3, which was a photograph of a completed tank on a scheme with which his firm had been connected, the tank appeared to be very much out of plumb, but as a matter of fact that was not so, all these tanks, placed on the sand mattress foundations, had remained perfectly plumb, and the leaning appearance of the tank was due to the camera not having been level when the photograph was taken.

The author had dealt clearly with the advantages and disadvantages of the multiple and unit systems of lay out. No doubt there was justification for the unit system where great areas of ground were available without practically any cost, but, where land was valuable, the multiple system would naturally be preferred on this score.

The reference to firewalls of concrete was of interest because, in certain cases, where old concrete firewalls existed, modern practice had resulted in their being blanketed with turf or soil, to prevent the danger to which the author had alluded. The angle of slope of 1 to 1 for earth firewalls, well turfed, might, of course, be steepened by the artifice of turf revetting, or other methods by which earth could be got to stand permanently at a steeper slope than its natural angle, but the question of extra cost of construction would then arise.

He did not know who had been responsible for the various oil depôts at Avonmouth, but apparently in some cases the methods adopted had not been very successful. It did not seem that the adding of extra weight in the form of ballast and cinders was very likely to ease the difficulties of the situation, unless they were so distributed outside the area of the tank as to prevent lateral spewing of the bad underlying strata, a most difficult result to achieve.

Reinforced concrete platforms, provided they were strong enough to distribute the total load over a larger area and so lower the intensity

Assoc.
Prof. Wilton

of loading, would, no doubt, be effective but expensive. It would be interesting to know if those responsible had tested the ground for supporting power, and then considered the possibility of arranging the tanks to suit this. He was glad to see that the author had referred rather critically, on page 55, to the use of concrete and reinforced concrete bases on a good soil foundation, because in some cases there was no doubt that unnecessary expense had been incurred by their use. He had not hesitated to use reinforced concrete in constructional work of various kinds when it was justified, but in some cases, there was no doubt, in his mind, that reinforced concrete had been used in constructional work merely because it *was* reinforced concrete, without a dispassionate consideration of the cost and suitability as compared with other forms of construction. The author's further reference to temporary timber trestles, on page 59, brought this question of economy in construction again into prominence. In this particular case the trestles were intended only to be temporary, but even for permanent work there were cases where timber could hold its own on the score of cheapness, both in first cost and upkeep. Provided timber structures were properly designed and provision made against lodgment of water, and the joints were treated with a suitable form of preservative before the several parts were bolted up, it was extraordinary how durable they were and what rough treatment they would stand.

Long distance pumping of oil referred to by the author at the end of the paper had, of course, been a commonplace abroad but not in this country. No doubt the analogy of the long distance pipe line from Egypt to Palestine across the desert, along which water was pumped to supply the British Army, and with the difficulties of which the author had been very familiar, had brought home to the average Englishman the possibility of conveying liquids for long distances by pumping through pipe lines in a way which any account of the long oil pipe lines abroad would hardly have succeeded in doing, and the publicity recently given in the non-technical press to the Havre-Paris oil pipe line, would, no doubt, also do much to awaken interest in this method of transport of oil.

15th December, 1920.

W. BRODIE, M. Inst. C.E., Past President,
in the Chair.

The Council reported that the following elections had been made :—
REGINALD FRANCIS BAKER, DARWIN BATES, ALLAN PETER HITCHENS,
B. Eng. (*L'pool*), and JAMES FOSTER PETREE, as *Members*.

“Sound in Engineering and Navigation.”

BY W. D. KIRKPATRICK, A.M.I.E.E.

WHEN the subject of sound, for a paper for this Society, was first spoken of, the question was asked, “What has Sound to do with Engineering?” This is a difficult question to answer, but the converse, “What has Engineering to do with Sound?” can be replied to much more easily and in a very few words. Not nearly as much as the importance of the subject justifies.

The whole field of the science of sound is one which has been left by engineers to Professors of Physics, and is only associated with its co-relative partners, light and heat in a physics course, and it may therefore be pardonable to define what sound is, because to appreciate any subject in its true perspective this course is necessary.

Sound may be said to be the sensation produced in the ear by a persistent vibratory motion when transmitted through a medium. Again, the fact that sound travels in waves which are dependent for their length and form upon the medium carrying them has been but little appreciated for practical use.

It might be urged that what have been stated are so obvious commonplaces that there is no need to bring them within the scope of this paper, but when it is realised that the carrier of these sound waves bears such an important relation to both the intensity, the certainty, and the speed of the message, the whole aspect of sound transmission and the purposes for which it can be utilised, will at once assume a marked change.

Everyone is so accustomed to think of sound in air only, that other mediums for its transmission have been quite lost sight of, but when it is realised that sound waves travel four times faster in water than in air, and in some more dense mediums at still more speedy rates, sound transmission becomes an entirely new proposition.

SPEED OF SOUND IN VARIOUS MEDIUMS.

Air	...	...	...	1,142 feet per second.
Fresh water	...	...	...	4,700 " "
Salt water	...	...	...	4,900 " "
Steel	...	...	...	17,500 " "

The following simple experiment, showing the possibilities of sound transmission by water, will amply repay anyone who has not tried it. If the submerged surface of a basin containing water is scraped by the finger nail or a ring, a certain volume of sound will be heard, but if one or both ears are immersed in the water and the scraping continued, the volume of sound transmitted in the second case will be a revelation to those who have not tried it.

Water has other advantages as a transmitter of sound waves in addition to speed, because zones of silence are not experienced such as are frequently met with when using a syren in fog.

Sound waves in air are subject to atmospheric conditions, whilst those in water are not, moreover sound waves in water have been found to travel in beams, somewhat similar to the rays of a searchlight, when out of focus they are highly directional, and the determination of their course can be accurately measured in a manner not possible in air.

The best results are obtained, of course, in deep water, and where the transmitter and receiver are in exact alignment and no bodies are in the path of the wave forms, which, it must be noted, are capable of being reflected and refracted, just as light waves on a mirror.

It is to the development of the ubiquitous submarine that the world is indebted for much that has been achieved in the art of sound transmission and reception, because, as the importance of this method of warfare grew, so the necessity for communicating with friendly, and detecting the presence of enemy craft became more urgent. In the research work no possible line was overlooked which would be likely to offer a solution of these problems, and volumes would require to be written to describe even a tithe of the work accomplished.

In the course of the investigations it was discovered that all bodies moving through water make a characteristic note peculiar to themselves.

In this way a reciprocating engined boat emits a different note to that produced by a vessel fitted with turbines. Twin propellers produce a different tone to a single screw, and so on.

The well-known laboratory experiment of reproducing a sound from several similarly pitched tuning forks, when one is set in vibration, has its counterpart in the method employed in picking up sounds produced by vessels either wholly or partially immersed in water.

To equip a vessel to receive these vibratory waves, steel diaphragms carefully insulated from all internal vibration by means of rubber sheeting, are inserted into the ship's plating with the outer surface in contact with the water, well below the water line. The holes to receive these diaphragms are cut about $\frac{1}{4}$ -inch diameter larger than the diaphragm itself, and the indiarubber is designed to prevent all internal vibrations

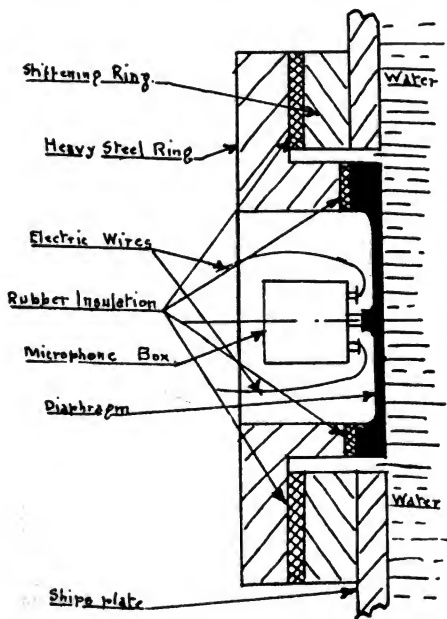


FIG. 1.

from affecting the microphone, which the diaphragm carries rigidly attached to it. This microphone is in the circuit of an electrical battery and head telephones, with a result that any sound waves which impinge upon the surface of the plate, produce corresponding vibratory electrical currents in the microphone, which can be heard in the telephones as a musical note of the same frequency as the transmitted sound.

This apparatus has been used in many forms in addition to the one described. Some of these hydrophones, as they are termed, were arranged to be towed singly, some in pairs for directional determination work, whilst others were arranged to be rotated, being mounted in a heavy lead casing, and fitted with baffle or screen-plates, so as to ensure that the direction of the sound waves could be ascertained.

The construction of them does not present any outstanding engineering difficulty beyond that inherent to delicate electrical apparatus on board ship. When fitted into the hull of a ship, two are used. They are placed as far below the water line as possible, and symmetrically opposite each other with regard to the hull, so that when used for directional work the best results can be obtained.

The detection of passing vessels at five miles can easily be accomplished in deep water but the intensity of the received sound varies with the type of ship. With a trained ear an accuracy of about half a point is possible in the determination of direction in the open sea.

Fig. 1 shows the general outline of a hydrophone as fitted into a vessel's hull. For clearness some of the details of construction have been omitted, but this figure shows the principle upon which this listening device is based.

Particular attention is called to the space round the diaphragm which there seems to be a great temptation to caulk over and thus defeat the object of isolating the machine from internal vibration.

This apparatus is, of course, primarily intended to receive the characteristic sound waves produced by any mechanically propelled vessel when moving through the water, and it is of interest to note here that had submarines remained the noisy creations that they were in 1914, the hydrophone would have easily driven them off the seas, but for very obvious reasons and by devious methods that noise had to be and was eliminated.

If it is intended to produce a sound of a specific character either for recognition or signalling purposes that is where the engineer comes into the question, and it will doubtless be recalled that the combination

fog signalling devices now in use in so many large vessels is due to a very worthy member of this Society.

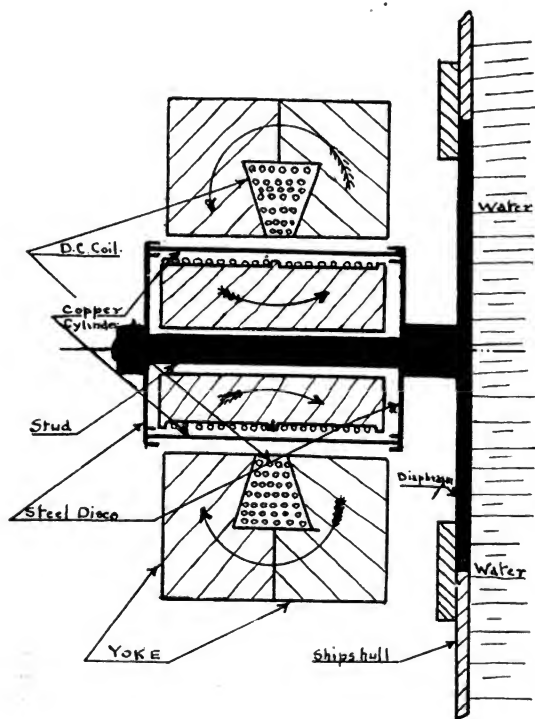


FIG. 2.

Where the problem has to be attacked beneath the water, although immensely increased efficiency is at once apparent, the difficulties to be overcome also multiply at an alarming rate.

Many and varied have been the schemes used to create the necessary vibration for sound transmission. Amongst those may be mentioned the Wrightson syren, in which a stream of water of about 30 gallons per minute is used, with a motor to rotate a cup perforated with holes, which operates as the ordinary syren. This is a very powerful device but requires rather a large pump to produce a sufficient disturbance necessary to produce sound. At first sight, the electrical solution would appear to be the one most likely of success, and several too hastily considered schemes of magnets supplied with alternating current acting directly upon a diaphragm fitted into the ship's side have been tried with very indifferent success. The fault with this arrangement is that the diaphragm is only pulled in towards the magnets, and relies entirely upon its elasticity to resume its normal relation to the plate, and apparently the diaphragms get either tired or lazy after being pulled about for a while, because the power absorbed during a prolonged signal is very excessive.

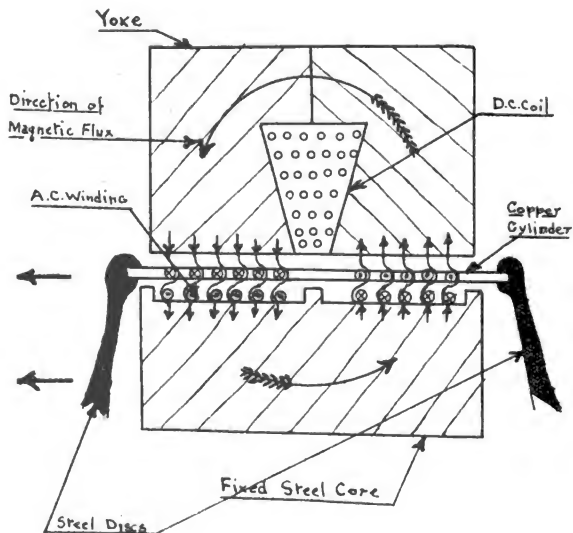


FIG. 3.

It is to an American that credit is due for the most efficient electrical sound producing device extant, the Fessenden Oscillator as it is called. This machine consists of a $\frac{5}{8}$ -inch thick steel diaphragm fitted into the ship's hull, with a vanadium steel stud screwed rigidly into the centre of it. This stud has two steel discs threaded on to it, which in turn support a thick copper cylinder, the whole being kept quite rigid by a nut on the end of the stud. These constituted the moving parts of the oscillator.

Fig. 2 shows diagrammatically the construction of the Fessenden Oscillator. The moving pieces have been outlined in black lines for the better appreciation of the several parts of the machine.

The fixed portions are (1) a solid steel core wound on the outside with two layers of wire, and (2) a solid steel yoke, which is in two halves and surrounds and encases the whole machine.

The oscillators are provided with two sets of electrical windings.

A coil in the form of a ring, which is supplied by direct current from the ship's mains, and a winding on the fixed core, which is wound one-half in a clock-wise direction, and the other half in an anti clock-wise direction.

Fig. 3 is an enlarged sectional view of the air gap, showing the copper cylinder and the two sets of windings. The arrows represent the flow of magnetic flux due to the direct current coil and the curved lines represent the condition, taking any instantaneous value of supplied alternating current when the flow is from the plane of the paper on the left through the plane of the paper on the right.

This core winding is supplied with alternating current from a special alternating current generator, and during transmission the action is as follows :—

The A. C. current causes the magnetic lines to move sideways, which induces by "cutting action" a current in the copper cylinder. The result of this current is that the magnetic flux becomes distorted, as shown in the figure, so that the cylinder is forced to the left. The next half-cycle of alternating current produces a distortion of the lines in the opposite direction, which causes the cylinder to be forced to the right, and thus a vibratory motion, having a period or frequency equal to the alternating current, is set up. So much for how it works, but how to make it work when fitted is another matter.

At this point the most important factor in the whole field of sound work has to be considered, namely, the syntony or tuning of the oscillator to the frequency at which it is required to work.

This syntony or resonance is an indefinable quantity, and to quote a well-known passage of "Molesworth" which occurs on the opposite page to the sizes of Standard Whitworth bolts and nuts, and runs, under the heading "Friction," "The laws of friction are not fully understood," nor, it might be added, are the laws of resonance.

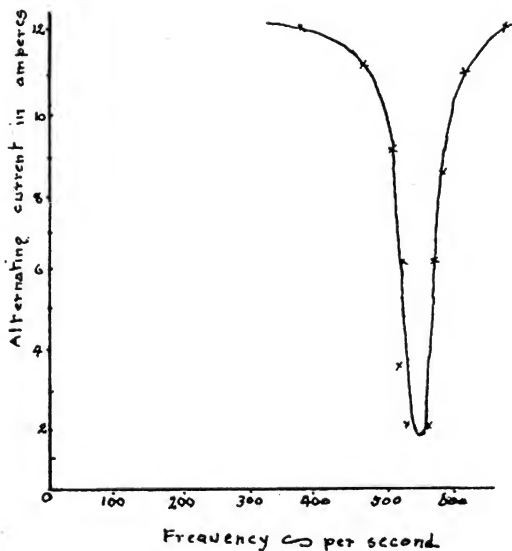


FIG. 4.

This process of adjustment or tuning can be explained by considering some instances of resonance. Take, for example, two equally loaded springs suspended in close proximity but without any connection the one to the other. If one of them is set in oscillation the other one will gradually pick up the vibratory motion until the time period of its oscillation equals that of the first, when it will in turn react upon the prime mover entirely damping out its vibratory motion. Thus the vibrations will be transmitted from the one to the

other until a state of rest exists. If a heavy pendulum is suspended it can be set into violent oscillation by even a puff of air, provided that the successive puffs are applied just when the pendulum is ready to receive them, neither before nor after.

The effects of resonance are also very noticeable in certain twin screw vessels, particularly when the turning moment on the shafts is unequally divided between the cranks and, say, the two H.P. cranks get turning over together.

It is also found when any high-speed vessel is running at so called critical speeds, when excessive periods of vibration at regularly recurring intervals can be observed, these periods taking place when the period of the engines and the ship coincide. Many other instances could be cited of the effect of sound on the flame of a candle for example, or an incandescent gas mantle, and instances have occurred where windows have been shattered by organ music, and even buildings destroyed by the direct effect of sound waves.

From the examples given it will be evident that in order to produce a maximum of vibration in these oscillators the period of the vibrating parts must exactly correspond with the period of the alternating current supplied to vibrate them.

A very remarkable proof of this can be seen by reference to the curve which connects the power used, when signalling, with the frequency, when the current absorbed drops to a very small value as the point of resonance between the natural frequency of the mechanical parts and the electrical current is reached, as shown in Fig. 4.

The actual method of determining the frequency at which resonance shall take place is not in the thickness of the diaphragm, as might be expected, nor in the weight of the moving parts as a whole, but in the thickness, and therefore the musical frequency of the steel discs supporting the copper cylinder.

These discs are most carefully turned to gauge and then afterwards tuned by reference to a standard; care being taken to leave a little in hand because of the impossibility of using them if perchance they are thinned too much.

It is of interest to note that the reduction of the frequency of the whole vibratory system is, in this case, effected by thinning these discs, which is in substance equivalent to increasing their natural frequency.

The frequency chosen for these machines to work at is 540 cycles in water, which is equivalent to treble "C" on the piano scale, and

the note produced is rather like that produced by a tin whistle, when heard in the receiving telephones.

This frequency is chosen for several reasons, but the most useful one is that telephone diaphragms have a liking to respond to it, and one of the harmonics, 1,080 cycles per second, and also a number of ship water noises, are about that frequency.

These oscillators can be used for reception as well as transmission, but before considering their use in this way it may be well to consider what a transmitted sound wave is, because but few have paused to think what a wave form or wave length really is. For the practical consideration of wave motion it is not essential to introduce complicated mathematics, although this is so frequently done.

A wave is essentially a harmonic movement in which the considerations of time and space only are necessary, and it matters not if it is a sound wave, a light wave, a heat wave, a wireless wave, or even a wave in water. Consider a man walking four miles per hour taking 130 steps per minute, what is his wave length? Approximately 2.7 feet.

Now if he reduces his wave length of 2.7 feet, he will require to increase his frequency if the speed of four miles per hour is to be maintained.

Wave forms can be divided into two classes: damped and persistent. The waves formed on the surface of still water when a pebble is dropped into it are of the damped character, because the amplitude or depth from the crest to the normal line is a decreasing quantity. The waves formed in the open sea due to a constant wind pressure are of a persistent character, persisting so long as the disturbing agent continues. The sound waves emitted by a bell are damped, while those from an organ pipe are persistent.

The sound waves emitted from an oscillator are persistent and have a certain definite amplitude so long as the power is supplied.

Sound waves have a definite frequency which determines the pitch, and a velocity which is dependent upon the character of the medium through which the wave is passing, so that the length of a sound wave can be actually determined.

Frequency 540 cycles per second.

Velocity in salt water ... 4,900 feet "

Wave length $\frac{V}{f}$ nearly 9 feet.

Having thus a definite sound wave form transmitted, it remains to pick it up. This, as previously stated, is done by the distant oscillator in the following way. The direct current coil is supplied with current, thus securing a powerful magnetic field through the copper cylinder, and because the diaphragm is in contact with the water the sound waves strike it, causing minute movements of the copper cylinder and discs to take place, and in turn causing rotary currents to be induced in the cylinder, and by transformer action, currents are induced in the windings on the core. This current is conveyed either directly or through an amplifier to a pair of telephones, where these variations can be heard as a musical note.

To return to the question of resonance, it naturally follows that the response will be greater if the incoming waves are of the same frequency as the natural period of the receiving machine.

In all vessels fitted with these oscillators, two are used, and like the hydrophones they are fitted as much below the water line as possible, consistent with the diaphragm being approximately vertical. They are also placed symmetrically opposite each other with regard to the hull, so that the best results can be obtained when used for directional work.

If the curvature of the hull is very marked at the only position available, care is taken to have the horizontal line of plating flush rather than the vertical. This obviates some of the troubles due to water noises caused by eddies passing the diaphragms when running at any speed.

It has been found that signals are received better from positions in advance of a listening ship when under way rather than astern of her. This is probably due to the interference to the wave forms caused by the action of the propellers on the water.

The dead beatness and control of the transmitted sounds with these machines is accomplished so exactly that Morse signals can be transmitted at speeds up to twenty words per minute if necessary.

Although this apparatus was primarily designed for naval use, the general utility of machinery of this character must be at once apparent. By its means vessels could be warned from dangerous coasts at much greater distances, and with much greater certainty, than is possible with the most powerful fog signals known. Moreover, it is not really necessary to have any specially designed listening apparatus for this purpose, because, at say three miles, the signals are quite audible in any quiet compartment below the water line when using a metallic rod in contact with the shell plating to receive them, the hull acting

as a diaphragm and responding to the impulses received through the water.

The subject of sound and all connected with it is so vast that it has been a matter of great difficulty to know what to include within the scope of this paper, but it would hardly be complete without some reference to some of the devices using sound, which have been perfected during the war for navigational work. The most useful of these commercially is probably the leader gear, invented by Capt. Manson, for guiding vessels through any channel by means of a cable laid on the bottom along the track which it is desired to follow. This cable is supplied from the shore with alternating current at any predetermined frequency, and the vessel using the apparatus has two frame coils about four feet square, one over each bow, inclined at an angle of about 15 degrees to the vertical. These coils must be fixed a short distance away from any iron work, but otherwise are very easily fitted and can be unshipped when not in use. The ends of the coils are brought in-board to a change-over switch, an amplifier, and pair of telephones on the bridge.

Steering is effected by "listening in" on the two coils alternatively, the signals being stronger on the side of the ship nearer to the cable.

The difference in the strength of the received signal is due to the screening action of the hull on the lines of magnetic flux which surround any cable carrying an electric current, the coil remote from the source not receiving the same strength of magnetic field as the one uninfluenced by the action of the steel structure. Several forms of relay are possible with this apparatus to avoid the use of telephones, red and green lamps, for example, being arranged in series with a relay to give a continuous visible indication of the vessel's position with regard to the track of the cable.

If such a device were in use on the Mersey, for example, it would be possible to pilot vessels in or out of the port by the main channel, and simultaneously guide, say, the cross river ferry services along prescribed tracks, by using different frequencies and, therefore, each receiving a different note in their telephone.

Frequencies of about 500 cycles per second have been found to give very satisfactory results with this apparatus. The Fessenden gear, as already stated, has a standard frequency of 540 cycles, but it is to the greater realm of vibratory motions equivalent to what is known as sound, but which are beyond the range of hearing, that the further developments of this science must be looked for. It has been found

that beams of sound having frequencies from 5,000 to 100,000 cycles per second, are the most powerful both for direct transmission and echo detection purposes, but it is not possible to give any detail of this apparatus in this paper.

If some of the possibilities in sound transmission detection and ranging can be appreciated by what has been said, the purpose of the author in bringing this subject to the notice of the Society in an endeavour to answer the question, "What has Sound to do with Engineering?" will not have been in vain.

The Paper was accompanied by plans which have been reproduced as illustrations in the text.

DISCUSSION.

The Chairman The CHAIRMAN said that he thought that after having heard the author they would agree that there could be no question as to his having made the subject a most interesting one to engineers and he was sure they would wish to accord to the author a very hearty vote of thanks.

Mr. Wall Mr. A. T. WALL remarked that it was quite evident that the author had gone into the matter in great detail, and that he wished them to have full information on all the points which he had touched upon. He personally did not know whether he might disagree with the author with regard to the vastness of the subject of sound in general engineering. He doubted whether the author had demonstrated that to them in his paper. The author might have referred to certain other subjects which came within the scope of the paper. He thought that the author had clearly justified in his paper the use of sound in warfare, but he did not think that many people would have occasion to use those methods in general engineering.

The question of hearing the sound more distinctly under water than in air was rather interesting. He had noticed it once in a bath; he heard a sound when above the water, but when he put his ears below it was tremendously enhanced. It was a good thing during the war that sound could be distinctly heard under water. He happened during the war to be connected with anti-submarine work, and one of the great planks in the anti-submarine platform was sound. His experience was that they did not always hear the sound they wanted to hear when listening on anti-submarine work, but they heard a sound. They had many experiences when they were trying to pick up the experimental submarine. They could hear everything else but the one they wanted to pick up, and the first sound was that of their own ship; in fact, one particular and special problem that he was then engaged on, was in endeavouring to shut out the sound of their own ship in order to hear the distant sound, and that was one of the biggest problems that had to be faced in the application of sound in anti-submarine work, also the effect of shoal water and the close proximity of the shore, it was extraordinary the tricks that these things would play on them. He thought that the author was optimistic. If they were listening for a quiet sound such as a submarine made, the

insulation shown on the blackboard for the hydrophone could hardly be claimed to be sufficient. The Americans did introduce a series of microphones which cancelled the ship's noise and only gave the distant noise. He had listened on this apparatus, and he thought that the general conclusion was that they were not very impressive, at any rate they were not able to satisfy the man whom they had to satisfy, and that was the naval officer. He thought that he had every reason to ask for an apparatus that was not going to be disturbed by accident. He must be very certain if he heard a noise that it was a submarine and not something entirely different. For instance, it was very easy to hear a surface ship with the propeller out of the water churning away at 10 miles, on an apparatus he had listened on, whereas a submarine running quietly along could not be heard one mile or less, and although the apparatus might be improved it was very difficult to pick out the particular noise. Mr. Wall

The author had spoken of the detection of passing vessels at a distance of 5 miles. He thought that the author was speaking of the Fessenden gear, but he certainly referred to hearing sounds on Fessenden at a great distance, and there was no mistaking the note of a Fessenden gear on picking up the noise signals on an ordinary listening hydrophone, but other apparati were introduced during the war for making very penetrating sounds and one of these was described in "Engineering" or "The Engineer" a short time ago, and he was connected with it during the war. It consisted of a steam whistle called "a cow"; he did not know why it got that name. It was in effect a steel diaphragm with a hole in the centre, and on the diaphragm was found a dead circle for the clamps, and when a jet of steam was passed through the hole in the centre the note given out was very strong and carried a good distance. It had been heard at 15 miles very easily.

The sound problem was different in submarine detecting than it was in the methods that the author had outlined in his paper. The submarine did not want to be heard, but in the paper they were trying to be heard, and that made an enormous difference. There was a very interesting thing showing the immediate effects of the sound. They might be listening to a vessel and might hear her quite plainly, but when she went astern they would not hear her at all, because the going astern muffled the sound. With regard to picking up direction, he was rather doubtful if the directions with the Fessenden were very good, but it certainly gave a greater degree of accuracy with two hydrophones placed on each side of a submarine or a ship. The

Mr. Wall author had mentioned water noises. He fully sympathised with him there. One of the first problems was to listen when they were going ahead, and it having been found that it was not possible to carry their hydrophones on the ship, the next step was to carry them in a towed body astern. It was very necessary to make that boat of good streamline formation, and they had to eliminate water noises on that body, because they were so near to the hydrophone. Incidentally they had to shut out their own engine noise. In that connection there was a point that would interest them. Early on in the war, when a towed body or fish, as it was called, was first developed, the vessel had to stop to listen, and the submarine, which was probably just cruising under the water at a knot and a half, could also hear the listening vessel on their hydrophone, and when the listening vessel stopped, they stopped; and when the listening vessel started again, they started again; many of these troubles were got over afterwards.

Mr. Gibson Mr. J. HAMILTON GIBSON observed that in connection with the transmission of sound through air as compared with water, he had heard it stated during the war that a screw boat could be heard under water very much better than a paddle boat. Perhaps the author could confirm this. He understood that at one period there were some very delicate anti-submarine experiments being carried out, and when they had got everything ready, much to the disgust of the experimenters, they found that a paddle boat was coming along and they feared they would have to postpone the experiments. When the paddle boat came nearer, however, they found that they could hardly distinguish the sound of the paddle wheel at all. They knew, of course, that water bubbles acted as a blanket and prevented the transmission of sound waves through the water and that was probably the reason. He was interested to hear the author's reference to the musical noises produced by "singing flames." They had all heard the sound sometimes made by an incandescent gas mantle. The author had given them a hint as to how the walls of Jericho fell; he told them that even buildings might collapse, due to musical sounds, if they happened to be of the right intensity and frequency.

He did not quite understand that by thinning the discs of the Fessenden apparatus the frequency was increased. He supposed that the author was right, but he should rather have thought that the thicker the disc the greater the frequency. He would naturally have thought a thin disc would be relatively weaker and would not vibrate with the same frequency and intensity. In connection with the under-water syrens referred to by the author, it was rather interesting to note that the

erosion which was observed round the holes of these syrens gave them the clue as to what was going on in the erosion of propellers, and Sir Charles Parsons had built up his apparatus from this hint. Cavitation was evidently occurring and the erosion was produced by the rushing in of the water to fill these cavities and producing enormous concentrated pressures of something like 80 to 100 tons on the square inch.

Mr. G. A. DICKIE wished to ask if the reason for the coil being made smaller at its inner diameter was to reduce the reluctance in the air-gap; and also in what manner vibration was set up in the diaphragm—did the entire apparatus vibrate as one mass, or was the vibration originated in the copper cylinder and then transmitted, mechanically, to the diaphragm by the discs and bolt.

- Assuming that the entire apparatus vibrated, would the author be kind enough to explain the function of the copper cylinder.

Mr. GEO. CARRUTHERS THOMSON had been very pleased to hear the author's clear survey of the subject. It was a long time since he had first heard of the subject of communication under water, and he thought that, in that case, it was made by means of a bell, to try to avoid collisions. It was used in a harbour and there was a bell placed near a buoy and it was rung, and the sound was carried a considerable distance. He thought that was the first practical application that he had seen of it for under water use and for giving intimation where a vessel was. It seemed to come off at times, but did not come off among the breakers, because they could not hear it. He thought that there was a good deal that could yet be done, and even in the case of that apparatus which had been put forward, he did not think it would be very long before it was more effective, so that they could get the sound waves more easily than they did at the present time. Of course it was quite true that in the intensity they had a greater speed. He had noticed that in experiments, if they came into almost a vacuum, they practically got no sound at all.

Professor W. MASON understood that the Fessenden apparatus was used not only for transmitting signals but for receiving them. He understood that the direction of an object, even to half a point, could be ascertained by the gear. One could tell roughly from what direction a sound came, by turning one's head so as to bring the ear parallel to the wave front of the sound vibration. Now this apparatus was fixed in the ship; how then could the direction be observed without turning the ship round or without moving the apparatus relatively to the wave front of the sound?

Prof. Mason

Another point was the remarkable speed at which signals could be received by this apparatus. He understood that something like 20 signals could be transmitted to the minute. Now, of course, the energy that was transmitted by a sound wave was small. He was not quite sure of the size of the apparatus, but the diaphragm and its appendages seemed large enough to possess considerable inertia. It would seem probable that vibration of the diaphragm would be produced cumulatively from the energy of the sound vibration in the water. Now although the tuning or resonant effect was present, one would expect that a considerable number of vibrations would have to be passed between the water and the diaphragm before the requisite amount of energy of oscillation had been communicated to the diaphragm. Then the vibration had to be damped and the succeeding oscillation to be responded to by the diaphragm, &c. Therefore it seemed to be a remarkable thing that so many distinct sounds per minute could be transmitted.

With regard to the point mentioned by several speakers concerning the frequency of oscillation of the sensitive plates (holding the copper cylinder) being increased by diminishing the thickness,—that appeared to him to be an anomaly, and he had evidently misunderstood the function of these plates.

In some recent papers read before the Society a short historical introduction had been given, and it might have been of interest to the members if the author had seen fit to deal briefly with the history of sound as applied to engineering. He had felt very greatly interested in the paper and he was only sorry that the author had not treated of some other applications of sound to engineering or warfare.

Mr. Dykes

Mr. JOHN DYKES confessed that he had not much experience with the subject, any further than trying it in dock from on board an Atlantic liner. A small boat was placed at a considerable distance from the ship and a bell was immersed in the water from the small boat and rung at intervals. One could, by listening from the instrument on board, easily distinguish whether it was on the port or starboard side by the intensity of the sound, but could not tell the distance it was off.

It reminded him of the old fashioned human listener, similar to the stethoscope, who by placing a steel rule between his teeth and a finger in each ear could locate an unusual sound in any part of the machinery in the engine room, such as a slack propeller, slide valve, packing rings in pistons, &c., by applying the end of the steel rule to where the sound came from and so locating it.

He was wondering if by this instrument one could tell the distance the sound came from, like the human listener could. Mr. Dykes

The CHAIRMAN said that towards the end of the paper the author spoke about the plan of passing guiding cables in the entrance channels to sea ports, and that appeared to be an excellent thing. Well, fortunately, in their own port, they were, he thought, in the position that their channel at the present time was not too tortuous or in any way unduly troublesome. Vessels could enter and leave the port of Liverpool without practically any trouble, so that with good lighting and sound signals, and with ample space, vessels could enter and leave without interference. The cross river traffic was a very important matter and many people would be glad of some absolutely sure means of securing safety in the crossing of the ferry steamers between Liverpool, Birkenhead and Seacombe, in such weather as they had recently been experiencing. It was a long time since any serious trouble had arisen in that connection with traffic, and they had to thank the men who were responsible for the working of their ferry boats for their extreme care, skill and experience. No doubt there would be some means devised for lessening the demands on those men, but whatever means were tried, if they were to be successful, they would have to take into account the currents on the Mersey, which varied at every hour and phase of the tide. That was the element in which the skill of their captains was fully exercised when they brought them safely across the river. The Chairman

The AUTHOR, in replying to the discussion, said that he was very gratified at the reception which had been accorded to the paper. It was very remarkable that a large number of the questions asked referred to the working of the Fessenden Oscillator, and particularly to the function of the steel discs in producing the vibratory movement of the diaphragm. The Author

Dealing with these questions generally, it should be made clear that the movements of the diaphragm were exceedingly minute, and one aspect of the design of the oscillator, which he did not emphasize in the paper, was the absolute necessity for the prevention of any vibration in any part of it excepting the portion which it was intended should vibrate. In this machine everything was so rigidly kept together that the only parts that could move were the copper cylinder, the discs, the stud, and the diaphragm. The discs played a very important part in so far as they transmitted all the vibrations of the copper cylinder to the stud and diaphragm, and they governed the speed of vibration, and therefore the pitch of sound produced because

The Author of their elasticity. The exact detail of the movement produced was so complex that it had only been worked by mathematicians after the results obtained by practical investigation were complete. Briefly, it was electrical effects in the copper cylinder that produced bending moments in the discs, which in turn were transmitted by the stud to the diaphragm, and thence directly to the water. That answered quite a lot of questions asked.

Some of the speakers had asked why the thinning of the discs should increase their frequency. He did not profess to know much about bells and bell ringing, but if in a peal of bells one was out of tune, the tuning was effected by thinning the lip of the bell, and thus altering the pitch of the offending bell. It was not possible by this means to bring the note down, but it could be put up or raised and thus increase its frequency, and consequently increase the number of vibrations per second.

The elasticity of the bell was increased by this method, but it was not possible to reduce it. In a similar manner, when these discs were being tuned, a little had to be left in hand, because, otherwise, not a few of them would be made too elastic and thus be spoiled. Mr. Wall had spoken about the results from sound transmission in shallow water. Particular emphasis was laid in the paper that deep water was necessary to get good results, and with reference to his remarks about hydrophones, it was quite true that Fig. 1 purposely represented a somewhat primitive form of hydrophone, because it was easier to understand than a more complicated one. The swinging of the ship was the only way in which they could get direction by means of these machines.

One speaker mentioned that people moved their ears by turning their head to locate sound. If one oscillator was fitted on each side of a ship, precisely the same result was achieved in the same way, because when the ship was swung through an observed angle, by judging the intensity of the signals received by the port or starboard oscillator respectively, the bow of the vessel could be turned toward the source of the sound. He was very glad that Mr. Wall mentioned the towed hydrophones, which were really one of the most important forms that the hydrophones took, and if it had not been for these designs, when the submarine menace was at its height, things might have been quite different.

It was very nice of Mr. Hamilton Gibson to say all the complimentary things that he did about the paper. It was, as he said, an extraordinary fact that a paddle boat did not give anything like the

same volume of sound in hydrophones as a boat fitted with propellers. There were one or two reasons for this, and the chief was that the speed of vibration was less and rather below the limit of audibility. He had not mentioned before that the limit of audibility varied between 50 and 20,000 in the human ear. If a paddle boat was making anything like 50 revolutions, she was going fairly fast, whereas 50 revolutions for a screw propelled ship was very slow, and therefore the actual note produced in the former case was too low to hear, and there was also the action produced by the floats striking the water and taking air down with them.

To refer again to the Fessenden Oscillator construction, when it was first proposed to reduce the frequency of vibration of the diaphragms, by thinning the discs, the idea was stated to be absurd, but when several other methods had been tried and had failed, that was the one finally adopted with highly satisfactory results.

Mr. Carruthers Thomson had mentioned about the submarine bells; they were actually in use on the lightships in the Liverpool Bay at the present time, but they, of course, only emitted a damped note and not a persistent one, and in consequence the sound did not travel in the same way as a machine of this description would cause it to do.

Anent his reference to sound in vacuum, if they could only arrange to keep all their alarm clocks in a vacuum they would get sleeping in peace.

In reply to Mr. Dickie's questions, the triangular section of the coil was arranged so that the pole face should be of maximum length. The copper cylinder was essentially made thick so that it should be capable of carrying the short circuited currents generated. If it was not thick, its resistance, taken circumferentially, would be too great. The action of the whole machine was dependent upon the amount of current produced in this cylinder. The wires carrying the alternating current were laid on the fixed steel core, and supported at the ends by a steel flange, which entirely prevented lateral motion. He hoped that the general explanation of the working of the machine, given earlier in the discussion, would answer the other constructional points raised.

In reply to Professor Mason, the sound signals transmitted by these machines, at say 20 miles, were as clear, sharp, and well defined, as a wireless signal in the ordinary sense. The Morse signals were clear and quite free from what might be called "fag ends." Each set of signals was clear cut and sharp, and the next signal the same in

The Author absolute precision. There was undoubtedly a large amount of energy to be absorbed at the conclusion of each signal, but the reversal of the alternating current winding, and the consequent short circuiting current produced, proved itself quite equal to the task. He had left out the historical setting of that paper purposely, because of making the paper too long and therefore uninteresting.

In conclusion, he would like to say something about the Chairman's reference to the Walls of Jericho, and also to the Mersey. He did not suggest that they should use or guide the ferry boats by that apparatus, but there was undoubtedly a need for something to guide the boats across the river during such weather as had been experienced during the present Winter, and there was an apparatus, not for transmitting sound signals, but for transmitting other beam signals, which would do that if it could only be adopted. It was an invisible thing, and as such was only capable of being picked up by those who had the proper apparatus for this purpose.

With reference to his remarks about the Walls of Jericho, he regretted that he had not any exact data as to the particular grade mortar used, but as a matter of interest recalled the fact that trumpets were requisitioned on that occasion.

5th January, 1921.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,
President, in the Chair.

The Council reported that the following elections had been made:—
LEONARD JAMES BANNING BLAKE, SYDNEY CHARLES BULLOCK and PETER
YOUNGSON, B. Sc. Eng. (*Lond.*), as *Members*.

“Water Power Problems.”

BY W. J. E. BINNIE,

B.A. (*Cantab.*), M. Inst. C.E., F.G.S.

GENERALLY speaking, problems connected with the utilisation of water for the production of power do not differ very materially from those which have to be considered in ordinary waterworks practice, but there are certain points of difference which it is the purpose of this paper to consider.

Financial considerations limit the impounding schemes which can be developed for power purposes to a great extent, as it is essential—

(1) That the run-off from the drainage areas to the point of impounding should be large.

(2) That there should be the opportunity of storing great quantities of water economically.

(3) That the water when stored should be at a high altitude.

(4) That the configuration of the country below the point of impounding should be such as to allow of an aqueduct which would provide a considerable head of water on the turbines in a comparatively short distance.

(5) That the position of the power house should not be at a prohibitive distance from large centres of population or from the sea.

On the other hand there is no necessity to take into consideration the suitability of the water for potable purposes.

BASIS OF DEVELOPMENT.

In ordinary waterworks practice it is usual to lay out the works so as to provide for that quantity of water which can be assured by means of the reservoir storage under all variations of climatic conditions.

This maintainable yield is fixed on the assumption that reservoir storage is provided sufficient to balance the run-off for the three driest consecutive years. In the almost invariable absence of actual gaugings of the streams to be impounded during such a period, the run-off of the three driest consecutive years is arrived at by inference from the average annual rainfall and the extent of the drainage area.

It is known that the average rainfall during the three driest consecutive years is about four-fifths of the average rainfall, and that the loss by what is known as "evaporation" is somewhere between 12 and 15 inches per annum in this country, hence a simple arithmetical sum gives the run-off during the three driest consecutive years.

The number of days' storage to be provided to balance the run-off during this period, so as to maintain a discharge from the reservoir at a uniform rate, was first established by the late Mr. Thomas Hawksley, and is expressed in the following form: $D = \frac{1,000}{\sqrt{F}}$ where F is the mean annual rainfall of the three driest consecutive years and D the number of days storage to be provided. By increasing the storage a larger yield than that of the three driest consecutive years would be obtained, and inversely by decreasing the storage the maintainable yield would be less.

The late Dr. Deacon devoted much time to the study of this question, and in his excellent article on "Water Supply" in the *Encyclopædia Britannica*, will be found a diagram which shows the yield per acre of drainage area with varying annual average rainfalls and storage capacities. It is unfortunate that Dr. Deacon never published his article in book form, as many water engineers do not seem to know of its existence, with the consequence that attempts are made to arrive at a solution, based on various widely differing assumptions.

When it is desired to develop a source for power purposes, it is obvious that if the works are designed only to use the maintainable yield of the three driest consecutive years, a large proportion of the available power would be sacrificed in a year of average or more than average rainfall.

By constructing a storage reservoir of enormous capacity, it would

be possible very nearly to balance the fluctuations of the average annual run-off, but the cost of providing such storage would generally be prohibitive.

The power might be required either for electro-chemical industries or for a guaranteed bulk supply.

In the former case it is not necessary to maintain an absolutely uniform rate of discharge from the reservoir, and by suitably designing the works it is possible to utilise nearly the whole of the average annual run-off, without a very large storage reservoir.

In order to minimise the loss by overflow from the reservoir, the power aqueduct should be made of larger carrying capacity than that required to convey the annual average run-off, so that during the winter months the amount of current produced is increased, and decreased during the summer months when the storage is drawn upon.

It might seem at first sight that there were disadvantages of working in this way owing to the difficulty in keeping the labour always fully employed, but in practice it is believed that no such difficulty arises.

The exact relation which the carrying capacity of the aqueduct should bear to the annual average run-off would differ according to the conditions, as the cost of the increased capacity of the aqueduct and power units must be considered in relation to the extra water utilised, in fixing the economic limit.

Under average conditions, which obtain in this country, the author has determined that it is economical to design the aqueduct so as to be capable of carrying 15 per cent. more than the average annual run-off.

Assuming such an aqueduct is provided, it is possible by means of diagrams extending over a period of years, sufficient to embrace all climatic conditions likely to occur, to arrive at the relation which the amount of reservoir storage provided bears—

- (a) To the average annual run-off which can be utilised.
- (b) To the average summer discharge which can be maintained by means of the reservoir.
- (c) To the minimum discharge which can be maintained during the driest years by means of the reservoir.

The curtailment of the author's professional work during the war afforded him ample leisure to undertake this somewhat laborious investigation with regard to the River Spean in the Highlands, upon which he was instructed to report by the Nitrogen Products Committee of the Ministry of Munitions.

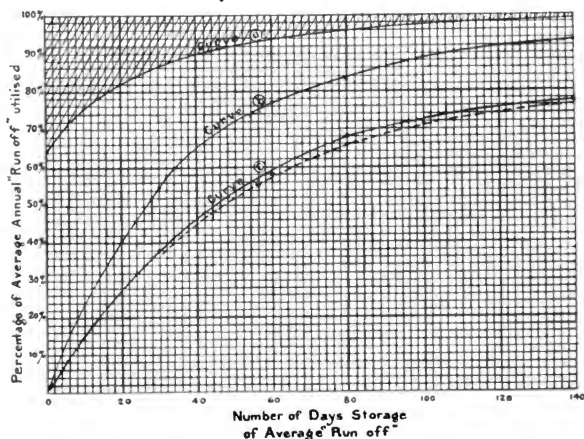


DIAGRAM NO. 1.

Showing the relation between the reservoir storage and the following :

(a) The proportion of the annual average "run-off" which can be utilised for power purposes assuming that the carrying capacity of the conduit is 15 per cent. in excess of the average "run-off."

(b) The average annual minimum discharged by the conduit in relation to the average annual "run-off."

(c) The extreme minimum discharged by the conduit in the driest year in relation to the average annual "run-off."

This diagram is based on the monthly rainfall records at Fort William, for the years 1881-1898, reduced to give an annual average rainfall of 75 inches.

The available rainfall allows for an average annual loss of about 11 inches, varying throughout the year according to a ratio derived from evaporation records, the minimum "run-off" assumed being that produced by 0.4 inches discharged from the drainage area in one month.

The hatched portion shows the loss by overflow.

The dotted curve shows the relation between the minimum discharge and the reservoir storage derived from actual gaugings of the river Vyrnwy, by the late Dr. Deacon, and described in his article "Water Supply" in the *Encyclopædia Britannica*.

Diagram No. 1 sets out the results by means of curves, (a), (b) and (c). Curve (c), i.e., the minimum discharge which can be maintained during the driest year, is the maintainable discharge which is assumed under any climatic conditions, i.e., the waterworks curve. This curve, which was arrived at quite independently, agrees very closely with the yield curve with varying storage for the particular rainfall given by Dr. Deacon's diagram, which is plotted by means of a dotted line for comparison.

The author was himself surprised to find how close the agreement was, which led him to a closer study of the annual fluctuations of rainfall over various areas in different parts of the United Kingdom, with the result that he is of the opinion that this diagram although based on data applicable to one particular area, can be taken as fairly well representing the results which would be obtained elsewhere in the United Kingdom, provided that the average annual rainfall was not less than 50 inches or thereabouts.

In order to prepare such a diagram with absolute accuracy, it would be necessary to have accurate gaugings over a long series of years, which did not exist in the case of the Spean River. It appeared, however, that an approximation to the actual monthly run-off in the absence of gaugings could be obtained from the monthly rainfall records. The author has been collecting data for some years with the object of arriving at the relation which exists between rainfall and run-off during each particular month of the year in this country. The information so obtained has been applied to ascertain the probable monthly run-off in the case of several rivers which have been actually gauged over certain periods, and where the inferential run-off was compared with the actual gauging it appeared that agreement was sufficiently close to establish the fact that the monthly run-off can be arrived at from the rainfall records with a sufficient degree of accuracy, and this method was therefore applied in the case of the Spean River.

Several points of interest are brought out by the diagram :—

(1) It will be seen that the advantage to be gained by increasing the storage beyond a certain point is small, unless a constant load has to be met.

(2) The advantage to be gained by laying out the works so as to develop them on the lines indicated, is well brought out.

Cases occur in waterworks practice when, in the author's opinion, it would be advisable to depart from the "three dry years" precedent and to design the aqueduct of a larger capacity than that necessary to convey that quantity of water.

As an example: a good many towns formerly drew their supply from underground sources but have now obtained additional gravitation supplies. By designing the aqueduct carrying the gravitation supply so as to carry the annual average run-off, the quantity of water available from a given source would be increased by between 30 and 40 per cent. in normal years, if the rainfall over the drainage area averaged 50 inches, and a greater proportion if it were less. As the cost of the reservoir would remain constant, and the extra cost of the aqueduct is all that would have to be considered, the additional water could be gained cheaply.

To illustrate this point, let it be assumed that a source yielded for supply 10,000,000 gallons per diem during the three driest consecutive years for which the necessary storage had been provided, and 14,000,000 gallons per diem during an average year, and that there are also wells from which 4,000,000 gallons per diem could be obtained. If the aqueduct could only carry 10,000,000 gallons a day, then when that supply had been passed the wells would again have to be brought into daily use and the cost of pumping incurred, whereas if the aqueduct would carry 14,000,000 gallons per diem the wells would not have to be brought into use in an average year until the rate of supply exceeded 13,000,000 gallons per diem and not into continuous use until a supply of 14,000,000 gallons per diem were exceeded. In the author's opinion this point is one which will require to be carefully considered in the future, as the drainage areas available for large towns are by no means numerous.

CATCHWATERS.

The drainage areas at high altitudes, suitable for development for power purposes in this country, are to a large extent limited to the highlands of Scotland and to Wales, and it is not always that a suitable drainage area on which there is also a good site for impounding water can be found.

The use of catchwaters to divert the water from drainage areas on which no suitable site exists is therefore very often resorted to.

To construct such catchwaters of a sufficient size to divert the entire flow of the drainage area would entail very large expense, as they would have to be of such carrying capacity as to deal with floods of great magnitude.

Seeing that it is essential for the development of power from water that economy should be studied as the all important consideration, the author was led to undertake a series of investigations with the object

of arriving at the economic limit of carrying capacity in relation to the average run-off, as he was unable to find any guide from established practice.

From a study of actual daily gaugings of various rivers and streams which differed materially in the extent of their drainage areas and the average annual rainfall which fell on those areas, it became apparent :

(1) That the variations in run-off were similar.

(2) That the loss by overflow would be small, provided that the catchwater was capable of conveying four or five times the average annual run-off.

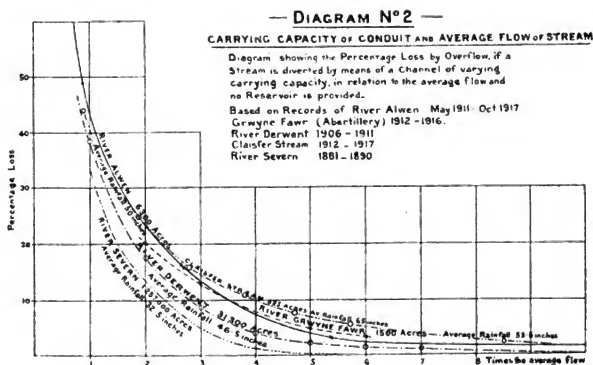


Diagram No. 2 shows what the actual loss would be as a percentage of the average annual run-off with catchwaters of varying discharging capacity for certain rivers and streams, and is of great interest. In the preparation of this diagram the author has been assisted by information supplied by Mr. Mansergh and Mr. Edward Sandeman.

AQUEDUCTS.

Aqueducts used for the conveyance of water present very little difference whether that water is used for power purposes or for domestic supply.

In the case of domestic supply it is now usual to filter the water just after it leaves the reservoir, as it is recognised that the filtration of the water not only renders it more suitable for domestic purposes but also removes certain organisms which form a growth in the interior of the pipes, thereby reducing their carrying capacity.

A certain loss of head is unavoidable if the water has to be filtered, and the loss is of little importance in schemes for domestic water supply, provided the source is at a sufficient altitude. Loss of head however means loss of earning capacity with a power scheme, and the practice is now often adopted of so designing the works as to utilise the additional head which can be obtained when the reservoir is full.

This involves the abandonment of conduits conveying water with a free water surface and the use of pipes or pressure tunnels.

When a large quantity of water has to be conveyed the modern practice is to employ pressure tunnels in place of pipes, where it is possible to locate such tunnels in sound rock.

The use of pressure tunnels—although claimed as a novelty in America—is in reality very old, as galleries under the beds of rivers connected by shafts with the aqueduct on both sides of the valley were used as far back as the third or fourth century to convey water under pressure in Mesopotamia.

The most important example of this class of construction is afforded by the new works for the supply of water to New York from the Catskill Mountains, pressure tunnels being used instead of pipe siphons, sometimes under enormous pressure, the siphon under the Hudson being situated 1,500 feet below the hydraulic gradient.

The principle adopted in designing these pressure tunnels is to locate the tunnel so far below the surface of the ground that the external pressure, due to the superincumbent rock, is not less than the internal water pressure. Great care has to be exercised to see that the rock is everywhere sound and to fill up all fissures, otherwise the lining will shear under the water pressure unless heavily reinforced.

Not only are these pressure tunnels cheaper than pipes, provided the quantity of water to be conveyed exceeds a certain limit, but the maintenance cost is negligible, nor do they deteriorate in value owing to corrosion. This has an important financial bearing, as the depreciation to be set aside is small and a life of at least 100 years can be assumed, whereas the author is accustomed only to allow a period of 20 years for steel pipes.

Another advantage which the pressure tunnel presents is that the aqueducts are often situated in regions where it does not pay to work in the open during the winter months, owing to climatic conditions.

Although the cut-and-cover conduit would be cheaper per yard run, the difference in cost, owing to conditions brought about by the war, might be much less than one would suppose.

The author is at the present time constructing sewers in tunnel

and cut-and-cover in the London clay in the neighbourhood of London. It was found possible to let the tunnel excavation piece work, whereas it was not possible to do so with regard to trench excavation, with the consequence that the cost of excavating the London clay in small tunnels for sewers six feet and five feet internal diameter has been only 1.6 times the pre-war cost, whereas the cost of excavating open trenches in the same material has been four times the pre-war cost. If such conditions are general it is obvious that the economic limit for tunnelling, formed on a pre-war basis, calls for revision.

LOAD FACTOR.

The author has frequently seen it stated that it is not economical to develop a water power so as to meet a variable load, and that the proper thing to do is to provide auxiliary plant to deal with the peaks. In the majority of cases which have been investigated it has been found that this is not true.

The total capital cost of a hydraulic power scheme is made up of :—

- (a) The works for impounding, land, and water rights.
- (b) The works for carrying the water to the turbines.
- (c) The power house and plant.
- (d) The transmission lines, where necessary.

The impounding works, &c., would cost the same whether the scheme were developed to meet a uniform or variable load, and represent, under average conditions, about 16 per cent. of the total cost, excluding transmission lines.

The cost of the other works representing, under average conditions, 84 per cent. of the total, if the transmission lines are excluded, would vary with the maximum load.

In the case of the power aqueduct (b) the variation would not be directly as the maximum load, i.e., if, for example, the carrying capacity of the aqueduct is doubled, it will not cost twice as much, but only about 1.5 as much for pressure tunnel construction, and this item represents as an average about 56 per cent. of the cost, if the transmission line is excluded.

The cost of the power house and plant (c) would vary practically in proportion to the maximum load.

The transmission line (d), if this were required, does not vary directly with the maximum load. The conductors would vary in cross sectional area very nearly with that load, but the wayleave would cost the same, and the cost of poles increases with the number or size of conductor in a much smaller proportion than the maximum load. As

a general rule, if the maximum load is doubled the cost of the transmission lines would be increased about 1·7 times.

When, however, the capital cost of a steam generating station is considered, it will be found that it varies very nearly with the maximum load to be met, provided that the generating sets are, in any case, of the most economic size.

Turning to the working costs, the power house costs per unit generated for a hydro-electric scheme are almost negligible whatever the load factor, if depreciation is not taken into consideration, whereas the load factor has a very important bearing on the coal consumption and wages bill in a steam power station.

If, however, the transmission line is very long and represents a large proportion of the total capital cost, it may be found that it is more economical to have resource to an auxiliary power station to meet the peak loads, as this station can be placed where the current is required.

It is impossible to lay down any golden rule and each case must be worked out on its merits.

AUXILIARY GENERATING STATION.

Supposing that a hydraulic power scheme is to be developed so as to make the best use of the average annual run-off, it will be seen from Diagram No. 1 that during the dry months, which are generally the summer months, it will not be possible to maintain the same supply of current as in the wet months unless in a wet year, and that a dry year may occur when there will be a serious deficit unless the storage capacity of the reservoir is very great.

Let it be further assumed that the current is to be supplied in bulk under a guarantee of delivery to one of the large cities. It then becomes necessary to consider whether it would be desirable to lay out the scheme so as only to develop current which can always be maintained, or whether to make as full use as possible of the average annual run-off.

Examination of the returns for municipal generating stations brings out the fact that, other things being equal, there is a greater load during the winter months than in the summer months, owing to the increased requirements for lighting, and an arrangement whereby a greater supply is given in the winter than in the summer would appear to suit both parties.

It sometimes happens, however, that climatic conditions, such as a very severe frost, greatly reduce the natural flow from the ground

during the winter and it would not therefore be sound practice to rely on being able to supply more current in the winter than in the summer.

In the majority of cases which present themselves for consideration, it will be found that the municipality already owns a large steam generating station, which would be closed down on economic grounds as soon as the current from the water power scheme is introduced. Such generating stations would, however, form a most useful adjunct to the water power scheme, and when the time had arrived when the demand for current exceeded the limits determined by curve *C* on Diagram No. 1 any deficit could be made up from the steam power station, until the maximum load which that station could deal with had been reached.

It is apparent that in such cases it would pay to lay out the scheme so as to make the best possible use of the average annual run-off, and to make such arrangements for the disposal of the current to the municipality as would permit of the procedure suggested, and even if no auxiliary station already existed it would be desirable to provide one, when the demand for current had reached the point when it could not be maintained under any climatic conditions.

USE OF RIVERS AND STREAMS WITHOUT STORAGE.

Although the number of large power schemes dependent on impounding reservoirs in this country is limited, owing to the fact that the conditions which are essential for the cheap production of electricity from water power on a large scale are not often found, there is an abundance of power in the streams and rivers which can be developed by means of small stations, and the author received instructions from the Water Power Resources Committee of the Board of Trade to report on this aspect of the question, on the assumption that no reservoir storage was provided.

STREAMS.

To obtain economically any appreciable amount of power out of a stream having a small drainage area, it is necessary that the bed gradient should be comparatively steep so that a considerable fall can be obtained in a small distance. This is the case with regard to most of the tributaries of the rivers in this country until they issue from the hilly country on their way to the sea, and power in small blocks could be produced economically at very numerous places.

If gaugings of rivers and streams are examined it will be seen that the fluctuations in flow are inversely proportional to the extent of the drainage area and, therefore, other things being equal, power can be more economically developed without storage on a large river than on a small stream.

It will also be found that the extreme dry weather flow of streams varies within wide limits, so that each particular stream should be examined on its merits.

In order to compare two extreme conditions, the author took the river Alwen as representing a stream of comparatively small drainage area with a very low dry weather flow, and the river Severn at Worcester.

The first point which emerged was that it would pay in both cases to instal turbines and auxiliary plant of sufficient capacity to maintain an output of current equivalent to that which would be provided if the average annual run-off were fully utilised.

The second point which was evident, was that whereas a fairly considerable fall was necessary in the case of the Alwen, a comparatively low fall could be economically developed on the Severn.

The efficiency and low cost of the modern turbines does not seem to have been realised by mill owners, and it is amazing to see the waste of valuable power in this country.

In conclusion, the author has to thank the Liverpool Engineering Society for the honour they have conferred upon him by inviting him to read a Paper, which has incidentally given him the opportunity of airing his views, and he hopes that he has been able to throw a little light on this most interesting and important subject.

The Paper was accompanied by diagrams, which have been reproduced as illustrations in the text.

DISCUSSION.

The PRESIDENT remarked that the Society was greatly indebted to the author for the very able paper which he had read that evening. It contained much original matter, and was a valuable contribution to the published information on a subject which was much in the public eye at present. The members present would probably be aware that the author had been engaged in connection with the investigations of the Water Power Resources Committee, and was responsible for a part of the survey work that was referred to in the first interim report of Sir John Snell's Committee. The President

In his paper the author had managed to interest two classes of engineers, who as a rule did not come into close contact, and by presenting a subject that concerned both the electrical and the water engineer he thought that the author would do both classes good, because he was asking the electrical engineer to look at the electrical problem from a different standpoint to that which he usually viewed his subject from. Similarly the water engineer was considering his own problem from a different point of view, and he could not help thinking that it was good for both classes of engineers that they should do so, because it broadened their outlook. There was no doubt that in the water engineering world they had to some extent been bound by very old established rules which had been handed down, and in many cases the conditions on which those rules were based had not been very closely enquired into. Now they were looking at the problem from broader points of view, and they were finding many important exceptions to the old rules that must be taken account of. In the same way, he believed that the electrical engineer would also benefit by looking at the power problem from some other point of view than that of coal fired stations. He did not know whether the electrical engineer would agree that if the author's ideas came into active operation it might be that the coal miner would not be such an important factor in modern civilization, but it was obviously of great importance that all schemes, which would conserve the national supply of coal, should receive full consideration. He had very great pleasure in proposing a very hearty vote of thanks to the author for his paper.

Mr. Dawson
Clothier

Mr. T. DAWSON CLOTHIER expressed his appreciation of the fact that the author had written his paper in clear English. They were accustomed to having things set out in an involved manner which did not readily lend itself to discussion. In the paper there were four items which interested him particularly; the term "run-off," which he took meant the total quantity of water available from any source of supply; the term "discharge," which was generally used as a water engineer's term for the amount of water extracted for use; the term "overflow," which seemed to be compensating water and the water that was allowed to continue down the river bed for irrigation and the other purposes a river served.

The "discharge" and the "overflow" he took it, were equal to the "run-off." The "aqueduct capacity" was the measure of the water which was intended for use for power purposes out of the "run-off." He would confine himself entirely to the point of view of what he would refer to as a power engineer, meaning an electrical engineer whose proper purpose was to collect all the power generated in any given district, irrespective of the method of production, to convey it in the form of electrical energy over the district, and to secure the most efficient use of the potential energy available from its origin to the place of use.

The 15 per cent. excess aqueduct capacity was rather troubling him. He would endeavour to make the reason clear in the following manner. If they examined the industrial power supply for any particular town or district, they would find there was a difference in the price of energy, roughly as 1 to 3 to the ordinary user, and an extreme price between the power that was supplied to the user whose demand was under the most favourable conditions (which were not necessarily 24 hours a day: there were more favourable conditions) and at the other end of the scale such users as cinematograph, church or domestic lighting. This extreme range was probably as 1 to 8. The difference in these prices did not represent the difference in the profit that the power engineer took. It represented in some measure the difference in the cost of producing power to meet the required conditions. Now if the water engineer set himself the problem of providing the energy that represented the lower rate, he was not going to offer so much saving in cash as might be done, and he should say that what at the outset should be aimed at was to produce a larger share of the power at the high rates and consequently increase the value of the water power to the community.

The problem which the domestic water engineer had to face was

to supply for 24 hours—perhaps allowing now and then for a broken pipe—the maximum quantity of water which he desired to extract from the river at the minimum cost, and the water would generally flow at an average rate for the 24 hours. It was a comparatively cheap thing to do, and it was easy and comparatively inexpensive in every case to put up local reservoirs that would carry on for a short time without the main pipe line.

Mr. Dawson
Clothier

The water engineer for power purposes, however, should supply the power at the time the user wanted it. Now an aqueduct capacity of 15 per cent. excess over the minimum average quantity would neither use a large enough proportion of power available nor enable the best use to be made of even that amount.

He should say that in this country, to supply over large areas, steam and supplementary stations would be very necessary, anyway, the problem should be to use all the energy in the water and to use it at the time of the day that it was most valuable. He would say, for instance, the *least* aqueduct capacity that should be contemplated should be such that one-half of the normal average water could be used at a regular rate throughout the 24 hours of the day and the other half could be used during any 8 hours of the day. This would require an aqueduct capacity of twice the run-off, and for power purposes without extraction of water the entire run-off might be available. Preferably the aqueduct capacity should be even larger than that. Alternatively, if the water power could be best converted at a number of places the power could be as readily floated on a common network. The aim should be to use the entire power available and to do away with the overflow capacity.

He desired to plead for the largest possible aqueduct capacity, and thought that a more important factor in considering the use of water for power purposes than the minimum annual 24 hours flow, was the maximum daily flow, over, say, a period of three weeks, a factor that the water engineer in considering using water for general purposes would ignore except for the overflow provision necessary.

Mr. A. E. MALPAS said that it was with some diffidence that he rose to offer a few remarks on the paper that had just been read, as he could not claim to have had much to do with the inception of any water power scheme so far as the preliminary surveys were concerned, and it was with the question of preliminary surveys that the paper largely dealt. Since, however, such questions as load factor, power house plant and transmission lines were also briefly referred to, he trusted that the remarks which he had to make would not be judged

Mr. Malpas

Mr. Malpas to wander too far from the subject of the paper, more especially as the uses to which the power was to be put formed an essential part of the water power problem, and it was with that part of the problem that his experience was chiefly concerned.

He might say that he had had practical experience in connection with at least four water power problems, of greater or lesser magnitude, and all of them on the Continent.

By the opening of the paper he had been led to hope that the author had been fortunately able to discover some new source of water power in the British Isles, but this hope faded away as he drew towards the end of the paper. It was not clear whether the author was also the author of the Severn scheme, of which something had been heard of late, but, if so, it was to be regretted that that particular problem was not enlarged upon at greater length, more particularly from the financial aspect of the question.

The general impression conveyed by the paper was that there were no very great opportunities in this country for the development of water power schemes of any magnitude. He did think, however, that such small blocks of power as they had available in different parts of the country had not been utilised as they might have been. In Spain, for instance, one often came across small electric installations driven from small streams and rivers, giving light and power to centres of population near by. In England, he only remembered to have seen the installation on the river Dee at Chester, and that was of comparatively recent date, whereas the installation on the river Tagus for lighting the City of Toledo was of much remoter origin. In fact, Spain was reputed to be the home of the small water power installation for the lighting of towns and villages. Even to-day the famous Toledo blades were made by using power derived from that river through Francis turbines of small power up to 150 H.P. each, and he certainly thought that more could have been done in the past on the same lines in this country.

One great reason why this had not been so was, of course, the bountifulness of nature in granting them a plentiful coal supply, so that even 20 years ago, with coal at 7s. 6d. to 9s. per ton, the inducement to develop small powers was not so great as it was to-day. Even then, however, men's minds were becoming agitated with the necessity of conserving the coal supplies by increasing the economy of its use, in view of the fact that those supplies were not inexhaustible. Various estimates had been made at different times as to the life of the coalfields of this country, ranging from 50 years to 200 years,

which he believed was the latest published figure, but probably the 50 years was nearer the mark than the 200 years.

This led, as they knew, to the development of the large gas engine, and the process of low temperature gasification of coal, with the object of recovery of the valuable by-products of the fuel. Unfortunately the large gas engine had not, up to the present, been able to establish that place in industry that was hoped for it.

One of the largest of the installations on these lines was that laid down in Madrid, in 1903, and owing to this installation not giving the results expected of it, the unsuitable nature of the coal available being one of the reasons for the shortcoming, it was found necessary to go farther afield and install a hydro-electric plant, 100 kilometres away, to take over the load from the gas installation, which was later held in reserve in case of breakdown and as an auxiliary generating station on the lines suggested by the author on page 102.

A few brief details of this installation might be of interest. A dam was built across the river Tagus, at a point approximately 100 kilometres from Madrid, just below its confluence with the river Guadiela, the configuration of the surrounding country lending itself admirably to the object in view. The two rivers flowed through deep valleys with precipitous sides for a long distance up stream and just below the confluence broke out into open level country suitable for the site of the power house and the tail race.

The dam was built to give a head of 32 metres at the turbines and gave a very large reservoir capacity by flooding the valleys higher up.

Four 5,000 K.W. Francis turbines were installed and the current generated stepped up to 60,000 volts, from which pressure it was again transformed down, at the receiving station in Madrid, to the pressure of distribution, viz., 15,000 volts for the overhead distribution lines and 3,000 volts for underground cables on the shorter distributing lines. That installation was working to-day, so that he need not describe it further.

On another occasion he had to go into the question of high tension electric transmission for one of the copper mines in the South of Spain, when a steam generating set was installed, as the catchment area available was not suitable for the adoption of a water-power scheme. It was, however, necessary to build a dam to form a reservoir for the storage of water used in connection with the cementation process of copper extraction. He saw this dam under construction in the early period just after the preparation of the foundation and the work of building had commenced. He gave

Mr. Malpas the benefit of his experience and criticisms to those responsible for the work without apparently making much impression, with the result which they could see from the photograph which he had placed on the table, which showed the dam after it collapsed. He merely brought this case to their notice as showing that at least it was necessary to take some care and precautions when designing and constructing works of this description.

Some time later he had been engaged in the design and erection at Odda, in Norway, of an installation for the manufacture of calcium cyanamide, a nitrogenous fertiliser formed by the absorption of nitrogen in calcium carbide, electric furnaces of the resistance type being used for the absorption, the nitrogen being obtained by the liquefaction of air.

The power used was generated at 11,000 volts and transmitted to the works 6 kilometres away. The water storage reservoir was situated in the mountains, the aqueduct being cut through solid rock at a level of 430 metres above the level of the fjord, which served as tail race. The installation was a large one, using 6,000 H.P. for the manufacture of cyanamide, the carbide works absorbing 50,000 H.P. The air liquefied per day amounted to 100 tons, and the finished product turned out as cyanamide to 200 tons per day.

It had been finished shortly before the war and did good service in providing supplies of ammonia, obtained from the distillation of the cyanamide in special autoclaves, for the production of ammonium nitrate for the use of the Allies. The nitric acid used for the fixation of the ammonia was also made from the atmosphere at the large hydro-electric plant, using arc furnaces, at Notodden. This installation, as they knew, to-day was capable of giving something like 400,000 H.P.

The conditions of water power problems in Norway were somewhat different to those contemplated in the paper, since in most countries Summer drought conditions determined the output available in Summer, whereas in Norway, owing to the melting of the snows on the mountain ranges, the supply of water was in Summer a maximum, whilst in Winter the supply was still maintained, as the water in the reservoirs never froze solid but merely protected itself with an insulating coat of ice, which reached sometimes two metres in thickness.

With regard to the author's remark on page 95 as to the difficulty in keeping labour fully employed during the Summer when water might possibly run short, the question did naturally arise.

On electro-chemical plants producing fertilisers there being very little trade during the Summer, many of the men left to work on the

land. In the case of other plants, of course any deficiency had, where necessary, to be made up by standby plant using coal as the source of energy.

In connection with another group of copper mines in the south of Spain, where the catchment area had allowed the formation of a reservoir to store an average run-off per annum of 1,700,000 cubic metres or, say, 1,000,000 gallons per day, quite recently the necessity had arisen of installing a Pelton wheel of 225 B.H.P. for generating three-phase current at 6,000 volts for distribution purposes. The scheme was really one of reconstruction and involved carrying a pipe line round the hills for a distance of 1,800 metres, say rather over a mile, so as to be able to utilise the bed of a river as tail race, which would enable a mean head of 95 metres to be utilised at the turbine.

The scheme had been put in hand during the war, when steel or cast-iron pipes were practically unobtainable, so that a decision had to be taken as to the relative advantages of (1) an open head race, (2) a closed reinforced concrete pipe line. The use of wood for the pipe line was not considered to be practicable.

The disadvantages of the open race were that (1) a man would require to be in almost constant attendance at the valve on the outlet from the dam, to regulate the supply of water to the head race, and any neglect would involve either a shortage of supply at the turbine or a wastage of water; (2) the loss of head of the water in the dam itself, which, in the case under consideration, would amount to approximately 8 to 10 per cent. of the total power available.

The objections to the concrete pipe line were :—

(1) Its liability to crack under expansion and contraction due to temperature variations.

(2) Its liability to rupture under shocks set up by sudden changes of load.

No very definite account of previous experience in the use of reinforced concrete pipe lines being available, very serious consideration had been given to the problem, and it was finally decided that, the normal working pressure in the pipe line not exceeding 15 lb. per square inch, it would be justifiable to construct the pipe line in reinforced concrete. In coming to this decision he had the advantage of inspecting the last of the 1,000-ton reinforced concrete ships built by the Concrete Seacraft, Ltd., at Penketh, on the banks of the River Mersey, near Warrington, and was so impressed by the result that they decided to proceed with the concrete pipe line.

To avoid the liability to crack, the pipe would be laid in a shallow

Mr. Malpas trench and covered with the earth excavated to a depth of about 9 inches, and this it was hoped would avoid any serious trouble.

To ensure safety against water hammer, provision had been made at the end of the line where a junction with the steel penstock was made, to carry an extension of the penstock up the side of the hill to act as a stand pipe, the top of the stand pipe being made rather higher than the level of the water in the dam when full to overflowing.

In this way it was hoped that no excessive strains would be put upon the pipe line due to shock.

Provision was also made on the governor gear of the turbine itself to reduce the shock to a minimum by the use of a deflector working in conjunction with the usual spear rod, by which the water flow was not suddenly reduced on any change of load, but merely diverted from the buckets of the Pelton wheel, thus allowing time for the spear rods to work slowly and reduce the flow gradually.

With regard to details of construction, he might say that the inner diameter was 700 millimetres, and to ensure water tightness, cement lining pipes 50 millimetres thick had been made on the spot in a suitable place near the pipe route.

The steel reinforcement rings and rods would be placed over those lining pipes when in position, and the whole concreted up solid with mass concrete, to make a finished outside diameter of 1,000 millimetres.

A sketch showing a section at one of the inspection manholes might be seen on the table. It would thus be seen that the pipe line was more a culvert than a pipe in the ordinary sense.

In the case of this installation, the storage capacity in an average year was estimated to run the power plant about nine months of the year, and during the dry season a gas plant was being installed to take the load, and to act as standby in the event of breakdown.

Mr. Roberts Mr. C. H. ROBERTS had listened with much pleasure to what he considered to be a very valuable paper which should form a valuable contribution to the "Transactions" of the Society, seeing that Liverpool was within easy distance of the Welsh mountains and the water power resources of Wales. With reference to the author's remarks at the bottom of page 94 regarding Dr. Deacon's cumulative diagram and the article on water supply in the *Encyclopædia Britannica*, Mr. Roberts thought that the remarks that "many water engineers do not seem to know of its existence," hardly applied to the Members of the Liverpool Engineering Society, because in the "Transactions" of the Society (1891) there was a diagram almost exactly the same as Dr. Deacon's, which was described by Dr. Tudsbery of the Institution

Mr. Roberts

of Civil Engineers. It had been said by some sceptics that water-power schemes were uncertain and might be failures, and that owing to the difficulty of obtaining capital, steam power was generally commercially preferable, especially as steam power was often employed as an auxiliary. Personally he knew of cases where water power had been unsuccessful, but in the cases he had in mind the non-success was due to the want of appropriate engineering advice. He thought that it could not be stated too often that there was no class of engineering work the success of which was so dependent upon thorough investigation and sound engineering advice as the class which formed the subject of the paper. There were so many matters concerned and so much capital involved, that the strictest economy was essential. It was not by any means possible to develop economically all water power, neither was it possible to speak generally about water power propositions; every scheme had to be considered separately and worked out in detail.

He thought that Diagrams 1 and 2 were very interesting, and would be useful in the "Transactions" for reference. When the President referred to the cost of coal, he could not help thinking of and envying the owners of the Kinloch Leven power undertaking. 30,000 H.P. was developed at Kinloch Leven, and the costs were almost entirely capital cost. The owners in obtaining their power were almost entirely independent of coal and they were almost entirely independent of labour. He believed it was a fact that at Kinloch Leven the cost of power was not very much higher to-day than it was before the war, and he thought that the owners were to be greatly envied in these times.

Prof. Perrott

Professor S. W. PERROTT said that the paper seemed to have many interesting and useful facts in connection with hydro-electric problems generally. He had not had a varied experience of hydro-electrical schemes beyond being connected with one which had not been developed. In that case he had been connected with a scheme to utilise the water of the Shannon for this purpose. The Shannon was rather a bigger river than any referred to in the paper. Its catchment area was double that of the Severn and the rainfall was 37½ inches against 32 inches on the Severn. The great difficulty they had experienced in doing anything with the water there was to cover the period of the four dry months in the summer. The question of storage was a great difficulty for hydro-electric scheme promoters. The average run-off for the four summer months on the Shannon, taken for eight years, was only about 40 per cent. of the average run-off for the year, consequently, if any of the excess water was to be impounded

Prof. Perrott

to cover that long period of four months, it would mean very large reservoirs indeed. In the case of the Shannon, there were natural reservoirs in lakes of a very large size with a normal area of 100 square miles. The raising of these lakes one foot, provided, however, less than a week's supply in the aqueduct, which was, of course, for the very large flow of 10,000 cubic feet per second, and it seemed almost prohibitive to try and provide for the dry period if the same flow was to be maintained. If 5 feet was attempted the whole district around would be submerged. It was a very flat valley and the result of raising the lakes 5 feet was to submerge about 22,500 acres of fairly valuable land, and in the case of Lough Derg, about 40 or 50 jetties would also be submerged, which contributed still further to the difficulties. He could see that this would be a very serious difficulty in the case of a great many rivers where only a comparatively small fall was available, but the point suggested by the author of increasing the capacity of the aqueduct by 15 per cent. seemed an excellent one. He would like to know if that represented the maximum increase that could be adopted. It seemed to him that to use up most of the surplus water on the Shannon they would want a very much larger one, perhaps 30 per cent. increase.

Mr. Collis

Mr. W. H. COLLIS disagreed with the author on one point. The author had suggested auxiliary steam power stations. Mr. Collis thought that these water schemes ought to do their own work from beginning to end. Was it not true that the Victoria Falls power scheme had not gone beyond the auxiliary stage. In Switzerland, at some water power stations there was such an abundance of power that there was no suggestion of auxiliary plant. In fact, to find a steady load for the turbines the engineers used a water resistance consisting of iron or steel rods in the out-flowing water. He was a great believer in hydro-electric undertakings, not only from a power development point of view but also as an investment. He would refer them to the position of Consols and of hydro-electric bonds to-day and before the war. Before the war the bonds of the Cedar Rapid Company, a Canadian undertaking, were about par, allowing for the variation in the Exchange they were at practically the same figure to-day. Before the war Consols were 88, to-day they were about 50. He thought that spoke well for hydro-electric investments as a good thing. Their running expenses, speaking of Canadian undertakings, used before the war to be one-tenth of the gross income, now they had gone up to 25 to 30 per cent., and yet in spite of that the Montreal Light, Heat and Power Company, one of the largest hydro-electric undertakings

known, had been able to increase its dividends, to reduce its price to the consumer, and to raise the wages of its employees. He thought that also spoke well for water power. Mr. Collis

Professor E. W. MARCHANT thought that the crux of the whole matter was in the paragraph at the bottom of page 98. "Seeing that "it is essential for the development of power from water that economy "should be studied as the all-important consideration." That was, after all, the main factor in considering any of these schemes, and he would have been very interested if the author could have given them any information on the actual cost per kilowatt installed in any of the power schemes which he had under construction. When in America about 10 years ago, he had been very interested to see the water-power stations used for the supply of San Francisco. There was one station he went to see that was of extraordinary interest, where they had about 3,000 kilowatts station 250 miles away from San Francisco. The power was transmitted over a 60,000 volts line, and it seemed to him a very questionable matter whether that was really economical or not. The whole question really was one of cost, i.e., how much was it going to cost to put down the water-power station. If the cost was below a certain figure, no doubt it was going to pay. It seemed to him that the study of these hydro-electric schemes was, to a certain extent, speculative, in so far as it implied consideration as to whether it was more likely that the cost of labour was going to fall or the cost of coal was going to fall. It seemed to him that both factors—the cost of labour and the cost of coal—had reached their highest value, and whether it was real economy to spend a great deal of money on labour at the present time was, to a certain extent, open to question. As regards actual cost, if they took the cost of installing a water-power station at £80 a kilowatt, which was a high figure, but was the figure for some of the earlier Niagara stations, and they assumed that 12 per cent. was allowed for interest charges and depreciation and a 50 per cent. load factor, the cost per unit worked out at just over $\frac{1}{2}$ d. a unit for standing charges only. Now in addition to that, one had to consider that the cost of the transmission line in the hydro-electric scheme was always greater, because they could not put their station at the centre of gravity of their load, and therefore they had to add on to that the cost of the transmission line, that might amount to a very considerable sum. In most of the power schemes at the present day, in the big supply schemes, the cost of the transmission lines was about equal to the cost of the power station, so that would come to a great deal. He would like to ask the author whether the figures that Prof. Marchant

Prof. Marchant he had worked out in connection with any of these power schemes approximated to those results, because that was the really important consideration.

Mr. E. M. HOLLINGSWORTH remarked that the paper was a valuable addition to the "Transactions" of the Liverpool Engineering Society, and provided food for thought both for Water and Electrical Engineers alike. It emphasized the necessity for developing as far as possible water power in this country, and when one came to think of it, it was surprising how little had been done up to the present time, comparatively speaking, in that direction. The author certainly made out a case for the development of small undertakings, but if all the water power available in the British Isles was developed for electricity purposes it would barely touch the fringe of electricity supply as looked at from the much-talked-of super-schemes point of view.

As pointed out by Dr. Marchant, the author did not include in his paper any reference to the comparative capital cost of steam and water stations; further, no mention was made of the necessary capital outlay for the electrical transmission lines. That this question of transmission lines had an important bearing on the development of water power on a scale of any magnitude could not be denied, in fact, it was no secret that the retarding factor in the development of the super electrical schemes so lightheartedly put forward two or three years ago was owing to the capital cost of the transmission lines. Looking back it would appear that those responsible for the proposed super-schemes did not take into consideration at all the cost of transmission.

A previous speaker had referred to the water station at Kinloch Leven as being an ideal scheme, but as all engineers knew, this plant was put down for a special purpose, and that all the electrical energy generated at that station was used on the job for such special purpose.

He would like to point to the impracticability of this station giving a supply to any industrial area. As a matter of fact, the nearest town, Fort William, he thought, was many miles away, and even then the demand for such a small town would be very little.

He could not understand the author's statement in connection with the installation of an auxiliary station to the effect that, "If, however, the transmission line is very long, and represents a large proportion of the total capital cost, it may be found that it is more economical to have resource to an auxiliary power station to meet the peak loads, as this station can be placed where the current is required." For such a water-power station to give a supply to the

area where the current was required, transmission lines would, of course, be necessary, and the cost of increasing the copper to give the small additional demand during peak load time would be negligible. If the author required his auxiliary station to meet a shortage of water at the main power station from time to time, then of course the auxiliary station would be necessary. Mr. Hollingsworth

There was a reference in the paper as to an examination of returns from municipal stations going to show that the demand was greater in Winter than in Summer. He certainly could not agree with that statement. He was satisfied that if a return was taken of all the undertakings in the country, there would be found very little difference between the Winter and the Summer demands. He quite admitted that there was an increase in the lighting demand in the Winter time, but on account of the greater economy obtained by the use of gas-filled lamps, and the fact that in the majority of cases the lighting load did not represent more than 2 per cent. or 3 per cent. of the total, the lighting supply had very little effect on the demand.

He would like to ask the author about one of the necessary conditions for the water scheme, "that the position of the power house should not be at a prohibitive distance from large centres of populations, nor from the sea," and would like to know why it was considered advisable for the power house to be placed near to the sea.

Mr. CHARLES RETTIE was very interested in the paper, as he had had charge of a hydro-electric station in Canada. He wished to endorse the President's remarks regarding electrical engineers and civil engineers, and when at Messrs. Cammell Laird's, he had always tried to foster a good feeling with the engineers and gave them all the information he could on electrical matters, and they reciprocated by giving him all the information he wanted on engineering. With reference to the notes in the paper on the front page, he thought that a good deal had to do with the local conditions. He referred to the cost, for instance. He had just come back from Bettws-y-Coed, where they had a deep gully with water pouring down the hills from all sides. The cost of impounding that water would not be very great in proportion to the enormous power that would be derived. It would spoil the beauty of the place, but the time might come, as the price of coal increased and other costs, that it might be necessary to make use of such places. There was another point raised by the author which had also been referred to by Mr. Hollingsworth, and that was the question of using auxiliary stations. In California, where there Mr. Rettie

Mr. Rettie was no coal and no rain, and where they had to depend entirely on melted snow, one place used the same water three times over, passing it through three separate generating stations on different levels of the mountain sides, and then the water was sold for irrigation purposes. Under such conditions it paid them to have auxiliary steam stations, as the supply was intermittent, but in this country where coal was so plentiful it would not pay to have auxiliary steam stations as an aid to their water power supply, as the standby charges would be too great. There was another point he would like to refer to and put it in the form of a question. At Niagara Falls, the original power station was built about a mile from the Falls, the water entering the penstocks through a canal and driving the turbines 140 feet below, the generators being on the top. The discharge water from the turbines then entered a raceway which carried the water down to the river below the Falls. In the latest addition to the Niagara Falls Power Co., the station was built at the foot of the Falls. He wished to know if that was on account of the water having a clear discharge and if the water in the raceway interfered with the running of the turbines in the old station.

The Author The AUTHOR, in replying to the discussion, said that he would like to thank the President and the other speakers who had so kindly expressed appreciation of the paper.

He was very glad that Mr. Dawson Clothier had drawn attention to the 15 per cent. increase of carrying capacity of the aqueduct. It was not at all clear in the paper, but when he was referring to that capacity he had in mind an aqueduct similar to that used for the Kinloch Leven Works. In considering schemes for the supply of current to an industrial town he had taken a 40 per cent. load factor. There were two ways of doing it. They could either make the aqueduct of sufficient size to supply $2\frac{1}{2}$ times the average, so that they could convey the whole of the water from the reservoir to the turbines at the maximum rate required, or, if there was a good site for a service reservoir at sufficient elevation near the power house, the most economical thing was to discharge the water into that reservoir at a uniform rate, and only increase the number of pipes between that reservoir and the turbines required to meet the maximum load. It depended upon each particular case, but generally speaking, to meet the load factor of 40 per cent. it was necessary to have an aqueduct of sufficient size to do it. He did not mean that the maximum carrying capacity of the aqueduct was to be limited to 15 per cent. more than the average, but what he wanted to convey

was that in order to utilise the "run-off" fully with adequate reservoir storage it was necessary to have an aqueduct capable of conveying 15 per cent. more than the average "run-off." He thought that the definitions which Mr. Dawson Clothier gave as to what he meant by "run-off," discharge, overflow, &c., were quite correct.

Mr. Malpas had asked if he had anything to do with the Severn scheme. He had not, but he would like to take the opportunity of stating that it was put before the Water Power Resources Committee of the Board of Trade, by Mr. Meik, the Consulting Engineer to the British Aluminium Co., and Mr. Addenbrook, and this Committee put them in communication with the Ministry of Transport, but as far as he had read the reports in the papers, he had seen no acknowledgment of this fact.

With regard to there being no great opportunity of developing Water Power in this country, he was not at all sure about that, for this year there were two Bills to go before Parliament. One of these was for a scheme of about 85,000 H.P. continuous, and three-quarters of that would give them about 64,000 K.W. The other one, he thought, would probably be about the same capacity. The first one was to utilise the Spean River. The Ministry of Munitions had instructed him to prepare Parliamentary plans in 1917, but did not proceed with it, and the British Aluminium Co. were now taking it up to increase the power for the production of aluminium and they were going to put down works at Fort William. The other scheme was to utilise part of the flow of the rivers Tummel, Garry and Spey.

As to the disadvantage of working with an open conduit, this was very true. If the load was variable, and supposing that a decrease took place in the demand for current, the reservoir keeper would be at once communicated with by telephone to close down partially, but the rate of flow in the conduit would continue as before for a considerable time owing to its length, with the consequence that water would escape over the waste weir at the intake to the pipes to the turbines. At Kinloch Leven, where a conduit was used with a free water surface, he believed that it was found that they did actually lose a considerable amount of overflow, and that was one of the benefits of the pressure tunnel system, where all such loss was avoided. He had had no experience of ferro-concrete pipes, but certainly was not prejudiced against them, and probably they would have great advantages, especially having regard to the fact that there would be no corrosion. With regard to the coating inside with tar he did not think that ought to be necessary.

The Author

Mr. Roberts had referred to the British Aluminium Co., and he thought Mr. Roberts would be interested to know that they proposed, very greatly, to increase the available power and to establish new works at Fort William.

Mr. Rettie had spoken of standby station costs being prohibitive. It was owing to the price of coal, and in working it out, even with low storage for the hydraulic works, it did pay on account of the number of units which they could develop from the Water Power. It all depended upon the price of coal, but the present conditions were likely to continue for some time.

He was very much interested in hearing what Professor Perrott said about the Summer flow of the Shannon being 40 per cent. of the average during the four driest months. This was rather high, but it was probably due to the fact that there was a lot of natural storage in the lakes. He, personally, had been faced with the same difficulty owing to the flooding, but was able to avoid doing so, in certain cases, by drawing down the lake to obtain the necessary storage. In the scheme which the British Aluminium Co. had placed before Parliament they proposed to draw a loch down, as they could not raise it very much, on account of the railway running alongside it. In this way the storage was obtained very economically. Loch Treig, the lake referred to, was over 400 feet deep, and the sides sloped down very steeply.

On the question of the auxiliary stations brought up by Mr. Collis, he had nothing to add to what he had already said.

With regard to costs, before the war Kinloch Leven was an extremely cheap development. The scheme of this year was to get about 65,000 K.W., and the Parliamentary Estimate for the actual water part of it was £3,000,000 sterling. That did not include the power house, and that would work out at about £500,000.

Mr. Hollingsworth had said that the paper was rather pessimistic, but what he had said about the two Bills before Parliament this year was quite sufficient answer, and if Mr. Hollingsworth would read the first interim report of the Water Power Resources Committee of the Board of Trade, he would see that there were a number of storage schemes in this country which offered great possibilities. Mr. Hollingsworth had drawn attention to the fact that paragraph 5 read: "That the position of the power house should not be at a prohibitive distance from large centres of population, nor from the sea." He had already pointed out that the "nor" should have read "or." The reason of that was that in the one case, if towns were to be supplied,

the power house should not be at too great a distance from the centre of population, but if it was close to the sea, the power could be developed for electro-chemical industries. The Author

CORRESPONDENCE.

Mr. THEODORE STEVENS stated that every river one examined had such peculiarities that he agreed with the author (page 102, line 17) that "each case must be worked out on its merits." He considered that it was a real disadvantage for a technical paper to contain language loosely used. On page 94, line 20, *D* should have its unit stated. Diagram No. 1 had horizontal scale of "number of days storage of average run-off," but it did not say it was "*D*." Mr. Stevens

On page 97, the following statement was made:—

"Diagram No. 1 can be taken as fairly well representing the results which would be "obtained elsewhere in the United Kingdom, "provided that the average annual rainfall was not less than 50 inches "or thereabouts." This proviso excluded 83 per cent. of the area of the United Kingdom, as only 4 per cent. of England, 16 per cent. of Ireland, 35 per cent. of Scotland and 38 per cent. of Wales, enjoyed more than 45 inches average rainfall.

On page 97, line 17, the possibility of "absolute accuracy" in diagrams dealing with rainfall and run-off was suggested. The author was by no means alone in the suggestion of greater accuracy than was attained in engineering practice: e.g., the Report of a Nile Projects Committee used this word "absolute"* in the sentence, "The "Committee finds that the measurements at Aswan are direct and "absolute, and are the most accurate measurements that have ever "been made of the discharge of a large river."

Here Mr. Stevens queried the meaning of "direct and absolute." There appeared no statement that evidence was before this Committee concerning how accurately other large rivers had been measured, so he made no comment on that point; but having carefully examined the figures for discharge of the sluices under various heads, he found that since that Report was published the man on the spot had considerably improved the accuracy.

Taking the speed of water flowing through sluices by current meter, and then, with all usual allowances, calculating the quantities was neither direct nor absolute. It was as good a method as was needed and *too extreme* a degree of accuracy was not required, but the loose use of words was apt to mislead.

* "The Times," London, 28th February, 1919.

Mr. Stevens

Again, in the "Proceedings" of the Institution of Civil Engineers, Vol. 194, it was stated that the Aswan dam was pierced by 180 sluices, the lowest sluices at 87·5 metres above sea level measuring 7 metres high by 2 metres wide, the highest measuring 3·5 metres by 2 metres at 100 metres above sea level. It naturally followed that water, after passing sluices, fell through various heights.

The minimum flow was 18,000 cubic feet per second, and the maximum more than thirty times the minimum. How would "absolute" measurements be taken of over half-a-million cubic feet per second? Each sluice group had some peculiarity that prevented "absolute" knowledge of its discharge. The knowledge was sufficient for practical purposes and reasonably accurate.

While evidence was before the Committee in London, the man on the spot, who had done all the measuring, schemed how best to check his former accuracy and to improve on it, and quietly carried through months of testing, and it would be of general interest when the time came for publication through the correct official channel.

At Mr. Stevens' request, Dr. H. R. Mill, LL.D., Director of British Rainfall Association, had, in 1915, examined his records of rainfall in Ireland during the thirty-five years, 1880-1914, and had estimated the loss by evaporation from free water surface in different parts of *England* on the average from about 16 inches to about 19 inches per annum and gave 17 inches, clearly as only a reasonable assumption, for evaporation over these catchments in Ireland.

Dr. Mill's results showed the following :—

SHANNON.

ERNE.

Square Miles	Average Rainfall Inches	Square Miles	Average Rainfall Inches
132	29·5	34	34·8
1,102	33	806	37·5
1,668	36·9	616	42·6
985	42	191	46·6
264	45·9	13	50·2
12	50·2	—	—
Above Doonass, 4,163 ...	37·4 mean	1,660	40·5 mean
Driest year, 1887	76 % of mean	1887	75 % of mean
Wettest year, 1903	129 % of mean	1903	123 % of mean

No other year showed deficiency as great as 20 % on either river. Mr. Stevens

				Shannon.	Erne.
Mean of 3 wettest consecutive years, 1912-1914 ...				108 %	109 %
" 3 driest	"	"	1887-1889 ...	87 %	89 %

Greatest number of consecutive years all with rainfall *above* average.

SHANNON.					ERNE.					
No.		Year.	% of mean.		No.		Year.	% of mean.		
5	...	1910	...	109	...	3	...	1882	...	117
—	...	1911	...	103	...	—	...	1883	...	104
—	..	1912	...	108	...	—	...	1884	...	105
—	...	1913	...	108	...	—	...	—	...	—
—	...	1914	...	109	...	3	...	1899	...	101
—	...	—	...	—	...	—	...	1900	...	110
—	...	—	...	—	...	—	...	1901	...	105
3	...	1882	...	114	...	3	...	1912	...	112
—	...	1883	...	108	...	—	...	1913	...	109
—	...	1884	...	101	...	—	...	1914	...	106

Greatest number of consecutive years all with rainfall *below* average.

SHANNON.					ERNE.					
No.		Year.	% of mean.		No.		Year.	% of mean.		
7	...	1887	...	76	...	7	...	1887	...	75
—	...	1888	...	93	...	—	...	1888	...	96
—	...	1889	...	92	...	—	...	1889	...	97
—	...	1890	...	95	...	—	...	1890	...	93
—	...	1891	...	96	...	—	...	1891	...	92
—	...	1892	...	99	...	—	...	1892	...	98
—	...	1893	...	80	...	—	...	1893	...	82
5	...	1905	...	86	...	—	...	—	...	—
—	...	1906	...	99	...	—	...	—	...	—
—	...	1907	...	98	...	—	...	—	...	—
—	...	1908	...	99	...	—	...	—	...	—
—	...	1909	...	91	...	—	...	—	...	—

There was no other occasion in Shannon or Erne (1880-1914) in which more than two consecutive years had rainfall either above or below the average.

The river Shannon had probably the best records kept during the longest period of any river in the United Kingdom. Mr. Stevens had studied these records over a seven-year period, but Mr. J. Chaloner Smith, M. Inst. C.E.I., had since elaborately investigated twenty-five consecutive years' records, 1893-1917.*

* "Proceedings," Inst. Civil Engineers of Ireland, 6th January, 1919.

Mr. Stevens The maximum flood he calculated to be 33,000 cubic feet per second.
 The average run-off 8,620 " "
 His rainfall average for 25 years was ... 11,040 " "

His rainfall averaged 36 inches over the catchment, his run-off 27·6 inches.

The difference, loss by evaporation, &c., was only 8·4 inches a year. This was much less than the author's figure "12 to 15 inches per annum," and Dr. Mill's "about 16 to about 19 inches."

If different authorities gave these different values, was it not proved that "absolute" was not the word to use.

Mr. Stevens had flow records by Mr. P. Wahlman for two years of the river Lules, Argentina, averaging 250 cubic feet per second with ten times that quantity at flood. The total annual flow was 8,000 million cubic feet, and storage available with a short dam 200 feet high for a quarter of the total annual run-off (area and rainfall not accurately known).

This, so far as the data went, agreed with similar streams in the author's diagram, No. 2, where Claisfer and Grwyne Fawr floods reached six times their respective averages; rivers Alwen and Derwent, ten times; river Severn, 5·5 times.

Figures were published in "Water," 20th May, 1918, of the storage available for Kinloch Leven works as follows:—"Head, 920 feet; rainfall, 70 inches; catchment, 55 square miles; reservoir, 4 square miles; water impounded for 30,000 horse power for 100 days."

A third of the annual total rainfall over the catchment was stored by a dam 86 feet high. He found only 28 feet average depth, plus allowance for evaporation, was needed if the area of the reservoir was correctly given.

The river Shannon had a catchment of 2,660,000 acres, more than double the figure given for the Severn, in Diagram No. 2, and its flood was less than four times its average flow; so that a conduit with a capacity of twice average flow would carry more than 90 per cent. of total flow (under 10 per cent. "loss by overflow" down river bed).

Surveys of the various possible diversions of the Shannon were made in this connection by Professor S. W. Perrott, M.A.I., M. Inst. C.E., of Liverpool University.

The working capacity Mr. Stevens had set for these conduits, 10,000 cubic feet per second, was 115 per cent. of average flow, the condition "determined to be economical" by the author (page 95, line 26), and a velocity of 7·5 feet per second was adopted.

The Tysse, in Norway, had 150,000 horse power developed years

ago, with a head of nearly 1,300 feet and three to four times the English rainfall. Storage of nearly a thousand million cubic feet existed, and could be more than doubled. Mr. Stevens

The AUTHOR, in reply to the written communication from Mr. Stevens, remarked that Mr. Stevens had stated :—"He considered it "a real disadvantage for a technical paper to contain language loosely "used. On page 94, line 20, *D* should have its unit stated. Diagram "No. 1 had horizontal scale of 'number of days storage of average "run-off,' but it did not say it was *D*." The Author

On reference to his paper the author was not clear as to what was meant by this criticism. The "*D*" referred to would appear to be "*D*" in the equation " $D = \frac{1,000}{\sqrt{F}}$ " where it was stated in the paper that *F* was the mean annual rainfall of the three driest consecutive years and *D* the number of days storage to be provided ; therefore the unit referred to was given.

With regard to the figures given by Mr. Stevens pointing out that the areas were small in the British Isles, where a rainfall of 50 inches and over obtained, this was correct, but certainly as far as Scotland, England and Wales were concerned, it was precisely in those areas where the best facilities existed for the development of water power.

The next point raised by Mr. Stevens was, that the author suggested the possibility of "absolute accuracy" in diagrams dealing with rainfall and run-off. On reference to the paper it would be seen that the statement referred to read :—"In order to prepare such a "diagram with absolute accuracy, it would be necessary to have "accurate gaugings over a long series of years, which did not exist in "the case of the Spean river."

If there had been accurate gaugings over a long series of years then there would be no difficulty in obtaining absolute accuracy in this particular case.

Mr. Stevens proceeded to quote Dr. Mill as follows :—"He "estimated the loss by evaporation from free water surface in different "parts of *England* on the average from about 16 to about 19 inches "per annum and gave 17 inches, clearly as only a reasonable "assumption, for evaporation over these catchments in Ireland."

It would appear that Mr. Stevens made Dr. Mill responsible for assuming that evaporation from a water surface was the same thing as evaporation from a catchment area. What was generally called "evaporation" loss from a catchment area was the ascertained difference between the mean discharge of the river and the quantity which

The Author would have been discharged due to the rainfall over the catchment area if there had been no loss. There were other factors besides "evaporation" to be taken into account.

Mr. Stevens quoted figures of rainfall relating to the Shannon and the Erne, apparently with the object of showing that the mean of the three driest consecutive years was not four-fifths of the average rainfall. If there was any meteorological assumption which met with the general approval of water engineers it was this assumption, but it did not necessarily follow that it was strictly true in every individual case where actual readings were examined. This was generally due to the fact that the records had not been kept for a sufficient length of time to embrace such a period.

Mr. Stevens proceeded to give figures which purported to show that the loss by evaporation, &c., over the basin of the Shannon in Ireland amounted to only 8·4 inches per annum. The author had read the paper contributed by Lieut.-Colonel Craster to the Meteorological Society, in December last, on the River-flow, Rainfall and Evaporation Records of the River Shannon. The catchment area of the river Shannon above Killaloe, where the river gaugings were made, amounted to 4,057 square miles, and it appeared that the only rainfall stations in the Shannon basin above Killaloe, for which continuous observations were available, were Birr Castle, 1881-1915, and Mullingar, 1875-1909, and that to compute the average rainfall, additional gauges at Limerick, Markree Castle, and Tuam, were used. Colonel Craster proceeded:—"It cannot be expected that these five records will give an accurate measurement of the total annual rainfall for the Shannon basin. None of them is situated in the hills, where the greatest rainfall occurs."

Colonel Craster, therefore, set aside the assumption that these gauges would give an accurate determination of the average rainfall, and proceeded to investigate the probable loss in other ways, the ultimate conclusion at which he arrived being set out as follows:—"The results of the foregoing investigation show that the flow of the Shannon corresponds very closely with the flow that would be produced by an annual rainfall of 45·71 inches, and an annual "evaporation from the soil of 16·88 inches."

The author had no personal knowledge of these records, but he did not accept the figure of evaporation loss given by Mr. Stevens.

19th January, 1921.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,
President, in the Chair.

The Council reported that the following elections had been made:—
ADDISON STANLEY BURDIS, CHARLES GREENWOOD, ANTHONY LAWRENSEN,
GEORGE LLOYD, ARTHUR ERNEST MALPAS, BRITON SELBY ROBSON, as
Members; WILLIAM HENRY EDMONDSON, JAMES RALPH JOHNSON, B. Eng.
(*Lpool*); and ANDREW MURRAY, as *Associate Members*.

“Impact Testing.”

BY Professor W. MASON, D. Sc. (*Vict.*), Assoc. M. Inst. C.E.,
A.M.I. Mech. E.

MATERIAL in many kinds of service is subject to impulsive forces, that is, to forces which are suddenly applied. For example, it is estimated that the stresses in 85 per cent. of the steel parts of a reciprocating engine are, more or less, due to shock of varying degree of severity. A force is said to be impulsive when it rises with great rapidity to its maximum and as rapidly subsides. A force may be repeated rhythmically 100 times per second, and yet the rate of increase of stress in the strained material may not be great enough for the action to be considered as impulsive. On the other hand, the impingement of small particles of the sand of a sand blast on, say, steel, is distinctly impulsive; the rate of increase of stress is high, while the maximum stress is sufficient to overcome the resistance of the steel to abrasion. The stress at the area of contact between two billiard balls colliding directly is estimated to be of the order of 20 tons per square inch. A feature of impulsive action is the difficulty or impossibility of calculation of the maximum force and stress, as well as of the rate of change of stress; and in many cases even a careful estimate may be wide of the truth.

An impact test does not admit of nice calculation of stress like, say, the static tensile test. But, for an impact test to be of use, it is not essential that it should furnish data for such calculation, since the forces due to the shocks and jars sustained by material in service cannot be precisely calculated.

It is well known that the mechanical tests in common use do not ensure with certainty that a material is not brittle. Satisfactory elongation and contraction of section in the tensile test, and even a satisfactory slow bend test, may be obtained for a material which shows brittleness under shock. It is remarkable that although brittleness is a dangerous, and toughness a very desirable quality, the impact test has not come into common use. The cold and temper bend tests very commonly specified may be effected either by pressure *or by blows*. The British Standards Association prescribes a "falling weight" test for rails; a specification from a body of high authority prescribes that steel castings shall be allowed to fall 12 feet on a hard macadam road or a floor of equal hardness, and several firms of steel makers make use of an impact test to detect faulty heat treatment. It is significant, however, that during the war, the Aeronautical Inspection Directorate instituted an impact test as an acceptance test.

An impact test might conceivably be any of the mechanical tests carried out with sufficient rapidity; but the tensile and cross-breaking tests appear to be the only ones that lend themselves with convenience to this requirement of velocity. Several investigators have carried out work on impact giving direct tension. Their apparatus has either taken the form of a swinging tup and anvil; or the test piece, with tup attached to its lower end, has been allowed to fall with its axis vertical, and on a sudden arrestment of the upper end of the specimen the momentum of the tup has taken effect and caused fracture. Obvious difficulties of measurement in the latter method have had to be met with rather elaborate devices, and the swinging tup method is much more convenient. For fracture by pure tensile stress the forces engaged are large; and the measurement of the work done to fracture is not so conveniently and accurately made as in similar tests by cross-breaking. Cross-breaking tests have been made by "single blow" and "many blow" methods. A repeated impact test, made in a machine like those of Stanton or of Roos, gives, perhaps, the nearest approach to testing under conditions of service. Such tests are, however, a lengthy process. Where, however, a few blows, say two or three, are given, the test has more of a qualitative than a quantitative character, inasmuch as the work required to be done to cause fracture is scarcely definite enough to justify measurement.

In France, Barba appears to have initiated testing of nicked specimens in cross-breaking with shock. About 1900, other French engineers had devised machines and made experiments, also on notched bars. The history of this mode of testing abroad and in this country

has been reported by Dr. Stanton and Mr. Batson in their paper* recently read before the Institution of Civil Engineers. The International Association for Testing Materials, after protracted discussions, at length recommended, in 1909, the use of notched specimens and the impact machine designed by Charpy; while in this country (where the above Association was not well enough known to carry authority) the difficulty of interpreting the results of the many-blow and other tests to destruction led also to the conclusions that a single-blow test to destruction was preferable, and that notched specimens enabled this test to be made with greater uniformity of result. Action as regards standardisation was not then taken, owing probably to certain important objections, the chief of which were the following.† The results of notched-bar impact tests were found to depend largely on the shape of the notch, on the type of machine used, and on the dimensions of the specimens; and the results, as a definite measure of toughness of material, were not considered conclusive. During the war, however (as already mentioned), a great development of notched-bar testing occurred, mainly owing to the adoption by the A.I.D. of this test as an acceptance test.

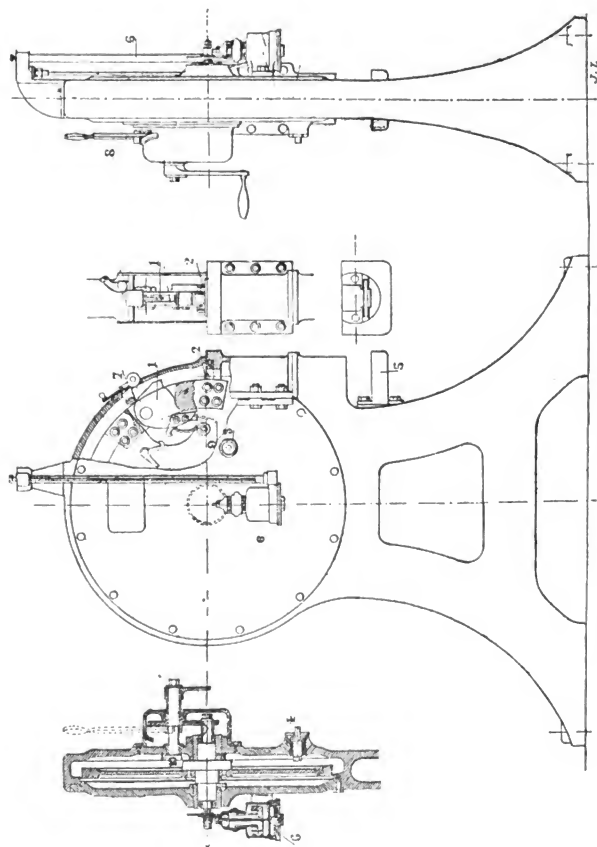
In this country the well-known Izod machine is the form of impact tester in common use; other types being used mainly for research purposes. Of the latter, the Fremont, Charpy, and Guillery, are the most important. The last named, used with the Fremont die for holding the specimens, appears to have some very definite advantages.‡ This machine is not well known to engineers in this country, and a description is therefore given here. (See Fig. 1.)

The specimen is held upon supports 22 m.m. apart at 2. It receives the blow from the knife edge 1 carried at the periphery of a wheel. The wheel is rotated by a handle until a suitable speed for the blow is reached. While the wheel is gaining speed, the knife edge is housed in the wheel and does not protrude from the periphery until the knob 4 is pressed. The speed of the wheel is gauged by the mercury column tachometer 6; the mercury being forced up the tube by a small pump driven from the shaft of the wheel. When the tachometer indicates the required speed, pressure on the knob 4 causes the knife edge to spring into position for the blow. After the blow the speed of the wheel is again read on the tachometric column, and the energy absorbed is calculated from the speeds immediately

* Characteristics of Notched-bar Impact Tests. Proc. Inst. C.E., Dec., 1920.

† See Stanton and Batson.

‡ Shock Tests and their Standardisation. Sir R. Hadfield and S. A. Main.



- 1 Movable Knife.
- 2 Specimen.
- 3 Disengagement Knob.
- 4 Engagement Knob.
- 5 Tray to receive broken specimen.
- 6 Tachometer.
- 7 Safety catch.
- 8 Lever for Clutch and Brake.
- 9 Engagement Cam.
- 10 Brake Shoe.

FIG. 1.—Dynamometric Tup. System—R. Guillery.

before and after impact and the moment of inertia of the wheel. The safety catch 7 is provided to prevent the wheel from being set into motion while the knife edge protrudes. In a later design of the machine the axle of the wheel, which rotates on ball-bearings, receives the support of collars which are brought into contact with the axle just before the blow is delivered, and are immediately withdrawn after the impact. The ball-bearing is thus relieved of shock, while the extra friction of the collars operates for so short a time as to be inappreciable.

Before mentioning the various aspects of the notched-bar test towards which experimental investigation has been recently directed, it is desirable to consider certain fundamental points. The object of the notch is to get a clean transverse fracture; without the notch, tough material would bend without breaking. Now the degree of toughness is measured by the work required to be done in some definite manner in deforming the specimen, and it is evidently necessary that for comparison, all material, both tough and brittle, should be deformed in the same way. Deformation to fracture is therefore essential, and the notch is a device for compassing this object in a definite way. Under the bending action large stresses are induced in the neighbourhood of the bottom of the notch. In a tough material flow will occur in this locality, allowing bending of the specimen accompanied by an absorption of energy. Cracking will always start in a tough material, at the bottom of the notch, and final disruption will be consummated with the absorption of an additional small amount of energy. In a brittle material it is possible that the crack may start elsewhere than at the root of the notch.

If reliable results are to be obtained, the tests of specimens of different sizes should be strictly comparable on some definite basis. In static tensile testing, geometrically similar specimens of the same material deformed similarly, and the work to fracture them is therefore proportional to their volumes. One of the factors making for comparable results under impact is evidently the requirement that specimens should be geometrically similar, not only in their overall dimensions, but also in the position, dimensions, angle and root radius of their notches. If the energy of fracture divided by the volume of specimen is to be a constant quantity for the same material, then the foregoing similarity as to dimensions must evidently be observed. Much work has been done recently on this point. (See Appendix.) It has been the practice of some Continental authorities to divide the energy by the area of section at the notch; but to this

custom of expressing energy per *square* centimetre there is obviously serious objection. A curious fact emerging from well conducted experiments on mild steel specimens of good quality differing only in width, is that the wider specimens required less energy for fracture than narrower ones ; but it must be noted that other materials did not present this anomaly, though the results were far from being what was expected.

The recent work just referred to has shown that geometrical similarity of specimen is by no means the only condition for comparability of results ; and herein lies one of the difficulties inherent in the impact test. Since the fundamental difference between a static bend test and an impact test lies in the rate of application of the force, this rate of application in a given series of tests should be the same ; or if this is not possible, the effect of different rates of application should be understood. But the rate of application of the stress *in* the material depends on the rate of deformation of the material under the force ; in purely plastic deformation the stress is proportional to the rate of flow. Hence it seems probable, and experiment * confirms this view, that the energy required to break a specimen depends on the rate of deformation in the test. Thus the work required would be greater with a higher rate of deformation provided the extent of the deformation was the same. It seems probable, then, that the energy per unit volume required to fracture similar pieces of the same material cannot be expected to be the same unless the rate of deformation is the same. Moreover, it is possible that the same condition of the stuff which precipitates cracking may not be reached if the rate of deformation is different ; in other words—there may be more than one condition of deformation and stress that will start a crack in the same material. If a material is incapable of plastic deformation, the pressure under the tup edge will be very large indeed ; this pressure will be propagated in the specimen as a wave, which will be reflected backwards as a wave of tensile stress. Such tensile stress must be a large factor in producing disruption.

In investigating the velocity effect, Sir R. Hadfield and Mr. Main used rifle bullets as tups, the striking velocities being as high as 2,870 feet per second. Dr. Stanton and Mr. Batson, using a pendulum machine with striking velocities up to about 30 feet per second, measured the actual time “*t*” of fracture by electrical means, which gave the time elapsing from the first contact of the tup to the instant

* Characteristics of Notched-bar Impact Tests. Stanton and Batson.

of complete severance of the two halves of the specimen. Taking the angle α (Fig. 2) to represent the deformation, and the quantity $\frac{\alpha}{t}$ to represent the rate of deformation, the latter investigators find, so far as they have gone, that the energy of fracture of similar specimens is more nearly proportional to the product of deformation and rate of deformation $\left(\frac{\alpha^2}{t}\right)$ than to the deformation (α).



FIG. 2.

Types of Fracture (approximately half-full size).

It appears from the foregoing facts, that since the effect of rate of deformation is still obscure, it is desirable to obtain, so far as possible, not only approximate equality of the striking velocities, but also to keep like equality in velocity of tup after impact. This would mean the use of a tup whose mass could be varied; it would entail some complexity in the scheme of testing, and at the best it is an awkward means of approximation to uniformity of treatment that would not suggest itself if the speed effect were understood.

Besides the foregoing fundamental points, there are several matters relating to the impact test which have been carefully investigated and elucidated. The shape and depth of the notch, and the radius of its corner, have an immense effect on the energy required for fracture. In general, it may be said that the more acute the angle, and the smaller the root-radius, the less will be the energy. This, of course, was to be expected, since the localised stresses are greater with sharper angle and sharper corner. The International Association for Testing Materials recommended the adoption of the "Charpy notch," a decision that appears to have met with approval, only qualified by the circumstance that this form of notch is not easily made, especially in harder materials. This circumstance appears to have led to the adoption of the V notch, which is easier to make, by the A.I.D. This V notched specimen is 2 m.m. deep in a section 10 m.m. by 10 m.m., the angle of notch being 45 degrees with a root-radius of 0.25 m.m. It is now specified by the Engineering Standards Association (Report No. 131, 1920).

Much work has been done on the testing machines mentioned previously, with the object of correlating and reducing to a common basis data obtained from their use. The machines differ in such respects as mass of tup, height of fall (i.e., in striking velocity) and distance between supports, as well as in variety in design. At the National Physical Laboratory similar machines, but of different capacity in striking energy, were constructed, in order that the conditions of similarity in the test of similar specimens might be as perfect as possible. When these machines were designed, it was thought that the law of comparison might be precise geometrical similarity in specimen and testing appliance; but, as already mentioned, results show that this condition alone is quite inadequate to give the required definite basis of comparison.

As showing present expert opinion concerning the test of notched specimens under impact, the author cannot do better than quote a conclusion of Messrs. Stanton and Batson, that "until the scale-speed factor has been evaluated, the chief value of the impact test will be "its use in detecting a dangerous condition due to faulty heat-treatment."

The Paper was accompanied by two plans which have been reproduced as illustrations in the text and by an Appendix, and was also illustrated by numerous lantern slides.

APPENDIX.

PUBLICATIONS ON IMPACT AND IMPACT TESTING.

Date	Author	Title of Publication	Reference
1895	Mansfield Merriman	The Resistance of Material to Impact	Proc. Inst. C.E., Vol. CXXII
1897	Ch. Frémont	Shock Testing	Académie des Sciences, 1897
1898	Ch. Frémont	Etudes de Chaudronnerie	Société des Ingénieurs Civils de France, 1898
1899	Ch. Frémont	Appareils nouveaux pour l'essai des métaux employés dans les travaux publics	Société des Ingénieurs Civils de France, 1899
1901	Ch. Frémont	Essai des Métaux par Pliage de Barrettes entaillées	Bulletin Société d'Encouragement pour l'Industrie nationale, 1901
1902	W. K. Hatt	New Apparatus for Testing Materials	"Engineering," Vol. LXXIV, p. 28
1902		Impact Tests of Notched Specimens (Messrs. Yarrow)	"Engineering," Vol. LXXIII, p. 513
1904	Seaton and Jude	Impact Tests on the Wrot. Steels of Commerce	Proc. Inst. Mech. E., 1904, Part 4
1904	P. Breuil	(Abstract of) The relations between the effects of stresses slowly applied and suddenly applied to mild steel	Journal Iron and Steel Inst., No. 1, 1904, p. 416
1906	Ch. Frémont	Résistance au Cisaillement des Aciers de Construction	Revue de Metallurgie, 1906
1908	A. Leon and P. Ludwik	Comparative Static and Dynamic Notched Bar Impact Bending Tests	Int. Assoc. for Testing Materials, 1908, No. 10
1908	Schüle	On Notched Bar Impact Tests	Int. Assoc. for Testing Materials, 1908, No 6
1908	T. Y. Olsen	New Forms of Pendulum Testing Machines	American Soc. Testing Materials, Vol. VIII
1908	F. W. Harbord	Different Methods of Impact Testing on Notched Bars	Proc. Inst. Mech. E., Oct.-Dec., 1908

Date	Author	Date of Publication	Reference
1908	Stanton and Bairstow	Resistance of Materials to Impact	Proc. Inst. Mech. E., Nov., 1908, or Collected Researches N.P.L., Vol. VI
1908	P. Breuil	Nouveaux mécanismes et nouvelles méthods pour l'essai des métaux	Revue de Méchanique 1908. Also see Proc. Inst. Mech. E. 1910, No. 2
1908		Notched Bar Impact Tests ...	"Engineering," 19th June, 1908
1908	H. C. Ehrensberger	Impact Test on Nicked Bars (in German only)	"Stahl und Eisen," April 1908, see "Engineer- ing" 19th June, 1908
1908	L. Guillet et Revillon	Impact Tests on Heated Steels ...	Int. Assoc. for Testing Materials, 1908, No. 7
1908	P. L. Revillon	Definition of Resilience in Impact Tests	Do., 1908., No. 7
1909	J. E. Sears	Some Experiments on Impact ...	"Engineering," 30th April, 1909 7th May, 1909
1909	H. F. Donaldson	Screw Threads (Impact Tests) ...	"Engineering," 12th February, 1909
1909	G. Charpy	Impact Tests... ..	Int. Assoc. for Testing Materials, 1908, No. 7
1910	Blount, Kirkaldy and Sankey	Comparison of Tensile, Impact Tensile, and Repeated Bending Methods of Testing Steel	Proc. Inst. Mech. E., 1910, No. 2
1910		Repeated Impact Testing Machine	"Engineering," 6th May, 1910
1910		Impact Testing Machine	"Engineering," 30th September, 1910
1910	F. Rogers	Behaviour of Steel under Combined Static Stress and Shock	Proc. Phys. Soc., London, Vol. XXIII, Part 1
1911	Ch. Frémont	New Method of Rail Testing ...	Génie Civil, 1911
1911	Committee of Int. Assoc. for Testing Materials	Standard Drop Testing Machine for Rails adopted by the American Railway Engineering and Maintenance of Way Assoc.	Int. Assoc. for Testing Materials, 1911, Vol. II, No. 4
1911		Shock Tests of Screw Threads ... (at N.P. Laboratory)	"Engineering," 24th March, 1911
1911		Impact Tests. Welds in Cast Iron	"Engineering," 22nd Dec., 1911

Date	Author	Title of Publication	Reference
1912	Ch. Frémont ...	Shock Tests on Notched Bars ...	Revue de Mécaniques
1912	A. Schmid ...	Influence of Shape of Bar upon Results of Notched Bar Tests	Int. Assoc. for Testing Materials (New York Congress) 1912, No. 8
1912	G. Charpy ...	Report on Impact Tests ...	Do., 1912. No. 9
1912	Ch. Frémont ...	Testing of Metals by Impact on Notched Bars	Do., 1912. No. 9
1912	M. Derihon ...	Notes on the Brittleness Test ...	Do., 1912. No. 9
1912	A. Gessner ...	Nicked Bar Impact Tests on Tough Steels	Do., 1912. No. 9
1912	N. Davidenkoff	Theory of a Tensile Impact Tester	Do., 1912. No. 10
1912	Andrew Gagarin	Automatic Impact Stress Strain Recorders	Do., 1912. No. 9
1912	H. Baucke ...	Behaviour of Copper under the Bending Test on Nicked Bars	Do., 1912. No. 9
1912	J. O. Roos ...	Some Static and Dynamic Endurance Tests	Do., 1912. No. 9
1912	P. H. Dudley	Testing Rails for Elongation and Ductility under the Drop Testing Machine	Int. Assoc. for Testing Materials (New York Congress) 1912, No. 11
1912	J. C. W. Humfrey	Intercrystalline Fracture of Iron and Steel	Journal Iron and Steel Inst., 1912. Carnegie Memoirs
1912		The Force of a Blow ...	"Engineering," Vol. XCIII, p. 159
1913	B. Hopkinson	A Method of Measuring the Pressure produced in the Detonation of High Explosives or by the Impact of Bullets	Trans. Roy. Soc., A Vol. 213
1914	Ch. Frémont ...	Mésure de la pression maximum instantanée résultant d'un choc	Revue de Métallurgie, 1914
1915	W. Austin ..	Impact Tests of Iron and Steel at High Temperatures	Journal Iron and Steel Inst., Sept., 1915 Also "Engineering," 1915, Vol. C., p. 455
1915	Sir R. A. Hadfield and G. K. Burgess	Sound Steel Ingots (Drop Tests on Steel Rails)	Journal Iron and Steel Inst., May, 1915
1915	R. Stribeck ...	Notch Shock Tests and the Law of Similarity	Zeit. des Vereines Deutscher Ingenieur, Vol. 59, No. 3

Date	Author	Title of Publication	Reference
1916	Report on Work of E. Höhn	Impact and Tensile Tests of Welds in Boiler Plates	"Engineering," 4th February, 1916, Vol. CI, p. 95
1916		"Nick and Break" Tests for Steel Rails	"Engineering," 30th June, 1916, Vol. CI, p. 629
1917	G. Charpy and A. Cornu-Thenard	New Experiments on Shock Tests	Journal Iron and Steel Inst., Vol. II, 1917, Also "Engineering," Vol. CIV, p. 346 & 371
1918	H. P. Philpot	... Some Experiments on Notched Bars	Inst. of Automobile Engineers, Apl., 1918
1919	S. L. Hoyt	... Toughness of Steel: Notch- Toughness	Journal of American Steel Treaters' Soc., Chicago, Vol. I, p. 247 see also Abstracts of Papers, Inst. C.E., New Series, No. 1
1919	W. H. Hatfield	... The most suitable Steels for Automobile Parts	Proc. Inst. Automobile Engineers, Vol. XIV, 1919-20
1920	A. Cornu-Thenard	... Etude experimentale des barreaux entaillés	Revue de Métallurgie, September, 1920
1920	Stanton and Batson	... Characteristics of Notched Bar Impact Tests	Proc. Inst. C.E., Dec., 1920
1920	Greaves and Moore	... The Single Blow Impact Test on Notched Bars	Do.
1920	Jones and Greaves	... The Effect of Overstrain on the Impact Figure of Steel	Do.
1920	Hadfield and Main	... Shock Tests and their Standardisation	Do.

DISCUSSION.

The PRESIDENT remarked that the author had given them a very interesting paper on a highly technical subject, and he had been able to put it in such a form that he thought most of them were able to digest some portion of it. It appeared from the author's remarks that there was a good deal yet to be learned about this system of impact testing, but he thought the author had said enough to interest them in it and they would follow future developments with greater interest by reason of this paper. He had occasion only a week or two ago to enquire into this subject of impact testing. As the members knew, water engineers made considerable use of cast-iron for their mains, and at the present time it was very difficult to get delivery of pipes of small diameter in this country. He found it was possible to get pipes from the Continent immediately, and incidentally they were much cheaper than English pipes. The question was how did these pipes compare with pipes of British manufacture. They were of lighter section, but on the other hand they were tested to a higher hydraulic pressure. He got particulars of their tests, which were really in accordance with the specification of the city of Paris. Instead of being subjected to a transverse cross breaking test, as was general in British practice, the test piece was required to withstand the blow due to a falling weight when carried on supports a stated distance apart. He had considered the French and English tests to see whether it was possible to compare the results. He had quickly decided that such a shock test could not be brought into line with a dead weight test, and he was therefore glad to learn from the author that this opinion was correct and it was not necessary to waste more time on the subject. It was obvious that in dealing with material of a brittle nature an engineer should have some measure of the degree of toughness which it possessed, and the system of testing so ably described by the author appeared to promise better results than any other he had heard of. He would ask them to pass a very hearty vote of thanks to the author for his paper.

Mr. E. A. ATKINS thought that they owed a debt of gratitude to the author for the very lucid way in which he had dealt with a very difficult subject, which in many ways did not lend itself to absolute clearness, but those who had done work in connection with the testing

Mr. Atkins of materials would glean a lot of useful information from it. What he was concerned with were two remarks in the paper, one at the commencement, "and the results, as a definite measure of toughness "of material, were not considered conclusive," and at the end of the paper, "the chief value of the impact test will be its use in detecting "a dangerous condition due to faulty heat treatment." What he had always been concerned about was that it was all very well to measure the toughness and brittleness of material, but what was the cause that brought it about. They wanted their testing laboratories to work in very close collaboration with the metallurgical department. In his firm they were testing all day and a good deal of work was done on the brittleness of the material, and if there was any that showed brittleness it was immediately tested by chemical and microscopical methods. By this method they were testing rivets. They found that after a material had been treated, which was a very mild steel of the very best quality, it showed intense brittleness, and on examination under the microscope they found that when the heat treatment had been carried out they got crystal growth. Afterwards it was heat treated in the proper manner, and they got small crystals and a very tough material. There was a very peculiar relationship between crystal growth and the brittleness of material. For instance, if mild steel was worked so that the area was reduced between 10 and 20 per cent., particularly at the lower percentage, then it had a tendency, if the heat treatment was wrong, to show large crystal growth, and he was inclined to think that a good many rivets, bolts, and what not were brittle, not because the material was bad, but simply because it had been wrongly heat treated. Then another cause of brittleness was due to hammering at the wrong temperature. For instance, if hot rivets were hammered at the wrong temperature, the heads would often come off. Another cause of brittleness was the phosphorus in materials. The brittleness depended upon two things: one was the percentage of phosphorus and the other was the smallness of the article they were dealing with. If they were going to draw down a piece of iron, the small diameter that they could draw it down to was pretty nearly in the inverse ratio of the phosphorus which the material contained. When they were dealing with steel rails and girder sections it did not matter so much, but in small sections he was quite sure that phosphorus played an important part. Phosphorus had a very deleterious effect on plates and sheets because it was one of the elements that tended to segregate, and he was pretty certain in his own mind that many failures in boiler and ship plates were due to

phosphorus segregation, for in his time he had examined many cases. Then there was another matter in connection with brittleness in steel. They could get two steels and the chemist would analyse them, and though he would have indetical analyses, yet they would have two entirely different properties. This was especially true in steel for making springs. They would find two materials in the formation of springs which would be entirely different; one would have two or three times the toughness of the other, yet in chemical analysis they were practically the same, and he was inclined to think that a good deal of the difference in their steel was due to the amount of dissolved oxide that had been left in the steel, and also probably the occluded gases, and he thought that accounted for the difference in rigidity that they often found in steel.

Mr. Atkins

[Mr. Atkins then showed a number of slides of specimens of the effect of heat treatment and other factors operating on steel plates.]

Mr. ATKINS, continuing, after explaining the slides, said that they would readily see that there were several factors that made for brittleness in material. There was first of all the factor of the steel work, and that was the most important, because they had tons of material with inherent defects and it was up to the steel people to remove it. They also had the defect from hammering and the heat treatment.

Mr. B. G. OXFORD said that he had considerable experience in testing of ship, boiler and engine steel, and while the usual method of tensile with cold and temper bend tests was not absolutely infallible, he doubted whether any other system of testing could give nearly such reliable results. In extremely rare cases one found brittleness in steel which had not been revealed by the tensile or bend tests. Possibly, this might have been detected by impact testing. Testing of materials was a commercial proposition and the simpler the system consistent with reliability, the better. The steel industry of this country had been developed and brought to its present high standard by tensile and bend testing. The results of impact testing shown by the author appeared to be an interesting laboratory investigation but lacking in the important quality of comparability. How important this quality was could only be appreciated by those conversant with steel works practice. Once the tensile strength of a sample had been ascertained, it was possible to predict with considerable precision what would be the test results of any thickness of material rolled from the same charge. Generally, the strength varied inversely as the thickness. Direct tensile and bend tests appeared to be the most appropriate tests to apply to constructional material, as these were the chief stresses to which

Mr. Oxford

Mr. Oxford they were subjected. Notching or even local reductions of section were always recognised as serious defects and avoided, so far as possible. Even in bolts a large margin of strength was allowed, and where practicable the screwed portion was left larger to compensate for this source of weakness.

He thought that it would be a great benefit if some different method of testing large forgings and castings could be devised, the present practice being extremely costly. The Brinell method for testing the hardness of materials appeared to be of some value in this direction. The tensile strength could be estimated approximately by this method.

Mr. Rowe Mr. H. S. ROWE remarked that from what Mr. Atkins had said there seemed to be at least two schools of thought which had varying ideas on the subject of brittleness. As a user of boiler plates, he sometimes came across cases of defects which could only be explained by such tests as the author described. The plates had shown quite good results under the ordinary tensile tests but failed after tests of the impact nature. A case came in his own experience where the steam drum of a well-known type of water-tube boiler fractured along a line of rivets, and an examination of the plates showed that it was due to local brittleness. A similar case had been reported by the Board of Trade in a recent report dealing with a boiler explosion that took place about two years ago at Rugby. This explosion resulted in the death of one man and extensive damage to a boiler house. Tests made upon some of the plates taken from the shell of this boiler showed that they were normal, but in the actual plate that failed, a series of small fractures had started at the bottom of the rivet holes and these fractures had gradually extended until the plate failed at a pressure under the ordinary working pressure of the boiler. It was not until the ruptured plate was taken out and carefully examined that the defects were found to be due to local hardness. The makers of the plates and the boilers both denied that there was any incorrect treatment in their works, and it would be interesting if the author could tell them whether the defect could have been found out by an impact test before the plate had been put into the boiler. He would like to ask one question on the paper. On page 133, the author spoke about the rate of deformation $\left(\frac{a}{t}\right)$. He took it that was the average rate of deformation, and wished to know if, during the test, there was anything to show whether this factor was constant or variable.

The AUTHOR, replying to the discussion, said that the President's remarks on the impact test for cast-iron were a surprise to him. He was not aware that even in France, which was the home and the place of origin of the impact test, that they made impact tests on *cast* iron. He supposed the test would be a falling weight test or a bending test on the same lines as the falling weight test as specified by the British Standards Committee.

With regard to Mr. Atkins' remarks, he thought that the members were very much interested in the causes of brittleness and concerning the particular effect mentioned of phosphorus in steel.

It was a new point to him that for small articles they must reduce the quantity of phosphorus between that which was allowable for larger diameters, in order that the strength might be maintained when the diameter was further reduced by drawing down. He did not quite understand what Mr. Atkins had mentioned with regard to the springs. He understood Mr. Atkins to say that the modulus of the rigidity might be very different even in springs of exactly the same chemical properties. Even in the raw material that seemed a very anomalous thing. They would hardly have expected that variation of the amount of oxide present would have been sufficient to have made much difference. The modulus of rigidity of almost all kinds of steel, excepting the fancy steels (that was of mild and carbon steels of all kinds), did not vary a very great deal, and it would be a very interesting point to ascertain why the springs differed so much among themselves in the quality of rigidity.

Mr. Atkins had approached the question of internal structure as affecting brittleness, whereas he had approached it from the point of view of the mechanical test. Of course both aspects were equally important.

In reply to Mr. Oxford, the main object of testing was, no doubt, commercial; but if they used a test why not have it on a scientific basis? If they were doing 100 tests per hour, the fact that they were doing so many was really a reason which called for a scientific basis of testing. Why should they not do the tests on a scientific basis and know exactly what the tests meant. The impact test, as it was at present, was a rough criterion of toughness or lack of toughness; whereas if the factors which were involved in the test were thoroughly understood, the test might be made of vastly greater signification, and might possibly be used in certain cases instead of the tensile test. It had been claimed for the Brinell Ball test, which was a test for hardness, that with a little further development of that test, tensile tests might

The Author

be rendered unnecessary, but until they got the scientific basis of these things they would never be able to use one test in place of many.

If they understood the scientific basis they would be able to reduce the number of tests and yet have quite satisfactory tests of quality. He quite appreciated Mr. Oxford's points, but at the present time they must, of necessity, use a number of tests. For example, if they retained the tensile test and they really understood the impact test, they could possibly dispense with the bending test.

Mr. Rowe referred to two schools of thought. He did not quite agree that Mr. Atkins' point of view and his own were two distinct schools of thought. They were merely endeavouring to throw light upon two aspects of the same question. With regard to Mr. Rowe's question about the boiler, it seemed reasonable to suppose that brittleness of the material of the boiler would have been shown if an impact test had been made, since the heating and cooling of the boiler would affect the plates but little, except perhaps at the seams. It was possible that some of the metal in the neighbourhood of the rivet holes had become hard, and that an unnoticed crack had been started. Mr. Rowe had raised the question, as to whether the rate of deformation varied during the period of impact. That expression for rate of deformation was used by Dr. Stanton as a mean rate; in fact, one might say, that particular quantity $\frac{a}{t}$ was used because there was no better measure available for the rate of deformation. The expression was a rough indication of the average deformation during the impact, and it was impossible to determine the relation between the maximum rate and the average rate.

He thanked Members for the remarks that they had made as to their interest in the paper.

2nd February, 1921.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,
President, in the Chair.

The Council reported that the following elections had been made :—
CHARLES JAMES BLAIR, WILLIAM REGINALD BRIDGWATER, CLIFFORD PLATT
GOURLEY, REGINALD HERBERT GRUNDY, REGINALD KAGAN, BENJAMIN
NORTH, ARTHUR WRIGHT PERRINS, LOUIS STEPHEN RICHARDSON, and
JOHN HAMPSOM RYDER, as *Students*.

“Tunnelling in Water-Bearing Strata.”

BY R. F. BAKER, M. Inst. C.E.

THE author in selecting the title of this paper prefers to make use of the wording “Tunnelling in Water-Bearing Strata” rather than the more usual term “Sub-aqueous Tunnelling.” The majority of tunnels are, to a certain extent, sub-aqueous, in so far as they are generally below the level of the water in the subsoil, but several tunnels have been constructed under rivers in clay or other impervious material where no difficulties have been encountered due to water, and the construction has been perfectly simple. Other tunnels which have been constructed remote from rivers but in water-bearing strata have presented considerable difficulties. The greatest difficulties arise when the tunnel is both sub-aqueous and through water-bearing strata, i.e., when it is constructed under a river in water-bearing ground, and the difficulties are increased if the river is tidal.

In the present paper, the author proposes to confine his remarks to smaller cast-iron tunnels, a number of which have been constructed within recent years for such purposes as condenser water intakes and discharges, sewers, and for carrying water mains under rivers, and where the only practical method of construction is by means of a shield under compressed air.

HISTORICAL.

It is well known that Brunel invented the tunnel shield in 1818, and by its help he constructed the Thames Tunnel from Wapping to Rotherhithe between the years 1825 and 1843 ; the length of this

tunnel was about 1,200 feet and the actual work was being carried on for about 10 years, so that the average rate of progress amounted to 120 feet per annum.

In 1830, Sir Thomas Cochrane suggested the application of compressed air to shaft sinking and tunnelling in water-bearing strata.

In 1864, the late Mr. Peter Barlow took out a patent for constructing tunnels by means of a shield and using cast-iron segments to form a permanent lining.

In 1869, the Tower Subway was constructed under the Thames near the Tower by the late Mr. Peter Barlow and the late Mr. J. H. Greathead. This tunnel was in London clay throughout, and a shield was used which was driven forward by screws worked by hand, and a cast-iron lining was adopted for the first time. The internal diameter of this tunnel was 6 feet 7 $\frac{3}{4}$ -inches, and cement grout was injected behind the iron lining by means of a hand syringe.

In 1886, the City & South London Railway Works were commenced, and on these works the well-known Greathead shields were used extensively, and compressed air was for the first time used in conjunction with a shield in water-bearing strata.

In 1888, the Mersey or Fiddler's Ferry Tunnel on the Vyrnwy aqueduct was commenced. This tunnel will, no doubt, be familiar to many members of this Society, and it is notable as the first tunnel to be constructed by means of a shield through water-bearing strata beneath a tidal river. After that, other tunnels were constructed in water-bearing strata by means of Greathead shields, similar to those used on the City & South London Works; but the next important development was in 1896, when Mr. Dalrymple-Hay introduced the hooded shield and the clay pocketing system during the construction of the Waterloo & City Railway. This method of tunnelling in water-bearing strata has now been almost universally adopted and the introduction of this system is a well marked step in the history of shield work. With the Greathead shield, when tunnelling in ballast or other open material, it was generally necessary to form a timbered length ahead of the shield, and when this was completed the shield was shoved forward into the length, and the whole of the timber was left in permanently. With the hooded shield and clay pockets, no timber is required except the vertical timbering to hold up the face, and the timber is not built in, but is used over and over again. This method of tunnelling will be described later in the paper, when the author will deal with details of the tunnel recently constructed under the River Dee, at Connah's Quay, carrying the mains for the Birkenhead

Corporation New Water Supply. As the Fiddler's Ferry Tunnel and the Dee Tunnel are probably well known to members of this Society, the author proposes to make some comparisons between the two tunnels, which will show the advances which have been made in tunnelling during the past thirty years.

FIDDLER'S FERRY TUNNEL.

Within the limits of this paper, it is impossible to do more than summarise the history of this tunnel. Briefly, however, the operations from start to finish occupied about 47 months. The first contractors had sunk the Cheshire shaft and had driven the tunnel from this shaft to a distance of 57 feet out of a total length of 805 feet, and had also sunk the Lancashire shaft to a depth of 97 feet when they ceased work at the end of 20 months. The second contractors were permitted to drive the tunnel at a higher level from the Lancashire shaft, and in a further period of 21 months they had driven 182 feet from the Lancashire side. Owing to difficulties which then arose, due to the buckling of the shield, the second contractors relinquished the work, but a new agreement was subsequently entered into with them to continue the work at prime cost under the direction of the engineer, the late Dr. Deacon. After this, the remaining length of about 620 feet of tunnel was driven and lined in four and a half months.

Before designing this work, borings were taken which indicated that the boulder clay commenced on the Cheshire side at about 66 feet, and on the Lancashire side at a depth of about 81 feet from the surface, and the engineer specified provisionally that the depths of the shafts should be about 86 feet and 104 feet respectively. The contractor was to drive the tunnel at a level at which there should be found to be a cover of at least 6 feet of the most impervious material, such as boulder clay, between the crown of the tunnel and the strata immediately overlying the boulder clay. A considerable amount of latitude was allowed to the contractor both in regard to the level at which the tunnel should be driven, and also in regard to the manner in which it should be constructed, but the engineer certainly contemplated the use of a shield, as he stated in the specification that it was desired that the cylindrical shield method introduced by the late Mr. Peter Barlow in the construction of the Tower Subway beneath the River Thames, and since then used with certain modifications by Mr. Greathead in the Subways beneath the Thames, near London Bridge, should be adopted in this case, but the contractor was to be allowed to make such modifications in the method as he thought proper. The

first contractor started the tunnelling approximately at the levels intended, i.e., in the boulder clay, no shield being used, but compressed air being employed. As already stated, when the tunnel had been driven to a distance of about 57 feet, water made its way into the tunnel and completely flooded it.

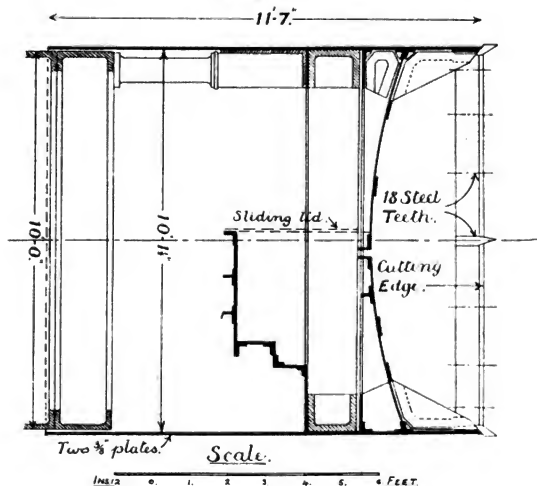
The second contractors decided to abandon the length of tunnel already constructed and to commence a new tunnel at a level of about 50 feet below high water. It was known that at this level the material would be water-bearing and variable in character, and the contractors installed a shield and compressed air. In this shield the diaphragm was closed by seven removable plates and there were hand-holes, also holes through which a hose pipe could be passed. At the bottom of the diaphragm a sluice valve was fixed. It was intended to loosen the material in front of the shield by means of water jets and wash the semi-fluid material through the sluice valve into the tunnel. This method proved unsuccessful, and after some trial it was abandoned. The excavation was subsequently carried on by raking out material through the diaphragm after removing the lowest of the seven plates referred to, and keeping the shield always shoved hard into the ground in front. The progress was very slow and eventually it was found that the shield was not sufficiently strong and had buckled badly in consequence. At this stage, the contractors withdrew, and the work was taken over by Mr. Deacon, who, acting on the advice of Sir Benjamin Baker, considerably modified the shield by strengthening the existing gussets and adding new ones; the cutting edge was also provided with projecting teeth. A water trap was fixed on the diaphragm fitted with a sliding lid which, when closed, completely shut the face of the shield. Fig. 1 shows a section of the shield as modified by Mr. Deacon.

It will be seen that the trap was formed by introducing a second diaphragm a few feet back from the main diaphragm, and the horizontal sill of the former was about six inches above the level of the opening in the main diaphragm. With this arrangement, provided that the pressure of air in the tunnel did not fall below the pressure of water outside the tunnel, no serious flooding could occur. Blows actually occurred on several occasions, but the sand and water soon filled the trap, and the blow was generally choked before any great amount of material could find its way into the tunnel. When the lid of the trap was removed, the miners were able to stand between the two diaphragms or outside the outer diaphragm, and the rate of progress considerably increased. The trap attached to the shield was a distinct advance in

the safety appliances in this class of tunnelling, and it has been adopted very successfully in other tunnels.

A delay of about 12 days occurred during the later stages of the work owing to a crack, which was in the original shield before modification, having become worse, and this necessitated cutting out and replacing a portion of the bottom of the shield. After this had been done, the tunnelling was completed without further mishap.

Fig. 1.

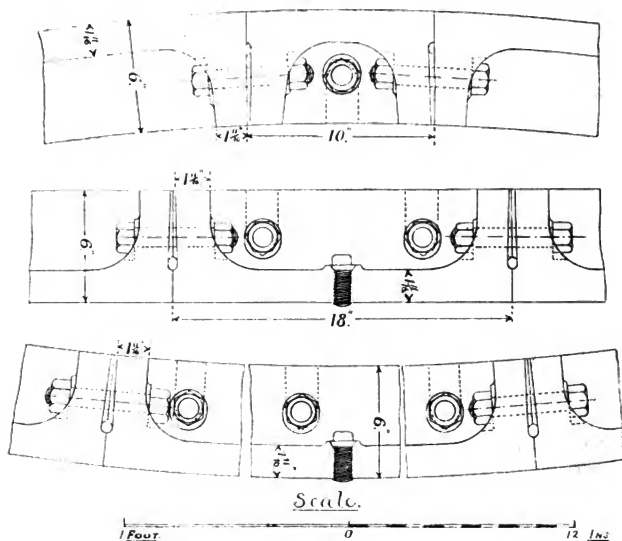


The cutting edge of the shield projected about three feet in advance of the diaphragm, but apparently the full benefit of the projection was not realised—as in the case of the modern hooded shield—and probably the amount of material excavated exceeded the volume of the tunnel, due to the fact that no special means were taken to hold up the face while the shield was being shoved.

The chief difficulties in the tunnelling seem to have been attributed to the rapidly varying strata encountered, with the result that the equilibrium at the face was constantly upset. The author is of opinion that these difficulties would almost disappear with the adoption of the clay pocketing system, and by keeping the vertical face close timbered and pugged.

In Fig. 2 details are shown of the cast-iron lining of this tunnel, from which it will be seen that the thickness of the metal was $1\frac{1}{8}$ -inch, which, compared with modern practice, is enormously heavy. The width of the rings was 18 inches and the depth of the flanges 6 inches. The weight of cast-iron per yard of length amounted to 4.1 tons. If a tunnel of the same size had to be constructed at the present time through similar strata, there would probably be a saving in weight of at least $1\frac{1}{2}$ tons per lineal yard, and the author is of opinion that the engineer to such works would have no difficulty in specifying the exact level at which he wished the tunnel to be driven and the methods to be adopted in its construction.

Fig. 2.



The construction of this tunnel was a notable achievement, having in mind that there had been very little experience of tunnelling in water-bearing strata to serve as a guide. It was at the time commonly asserted that the work was impracticable and would never be finished.

However, the difficulties were, in the end, very successfully overcome and many valuable lessons were learnt from the early mistakes and the repeated failures and successes which attended the construction of this work.

SHAFTS IN WATER-BEARING STRATA.

The first stage in the construction of a tunnel is generally the sinking of a shaft. The shafts for such works as the author is dealing with are usually cast-iron cylinders of uniform outside diameter, and they may be sunk in various ways. If the shaft is wholly through water-bearing strata, the cylinder is provided with a cutting edge, and it may be sunk from or near the surface by grabbing out the material from inside and adding weight to force it downwards, building up the rings as the sinking proceeds. If compressed air is eventually to be used in the tunnel, it is usual to do the latter part of the sinking under compressed air. By this method the whole of the cylinder is sunk from or near the surface to its final level.

A second method is to sink the cylinder by grabbing, as described above, for a certain depth, and when the cylinder is well into solid ground to construct air-tight decks and air locks, and finish the remainder of the shaft by under-pinning, i.e., the excavation is carried down below the bottom of the last ring to a depth to enable the segments of the lower ring to be bolted up to the underside of the ring above. If this method is adopted, the segments of which the cylinder is made up must be designed so as to be of a convenient size for passing through the air locks. This method can be adopted with safety in almost any material, and it is, in the author's opinion, the quickest and cheapest way of constructing small shafts in water-bearing strata, when subsequent tunnelling has to be done under compressed air. The inconvenience and expense of adding kentledge is almost entirely avoided and the under-pinning can be done very rapidly.

A third method which has been adopted is by under-pinning and the use of a simple form of shield consisting of a cutting edge and skin, screw or other jacks being used for forcing the shield down as the excavation proceeds. This method is practically vertical tunnelling by means of a shield.

Assuming that a shaft from which a tunnel has to be driven has been sunk by one of the methods referred to, the next process is to seal the bottom of the shaft, while the compressed air is still on, by means of concrete; sometimes a steel deck is also added. When the concrete has had sufficient time to set, the air is released and an open-

ing is made in the steel deck, to which the air locks are attached, to enable the shield for the tunnel to be erected in free air on a cradle at the bottom of the shaft.

In some shafts an opening is provided with a sleeve or hood projecting into the shaft for convenience in starting the tunnel, and forming a watertight connection between the shaft and the tunnel. The opening is closed during sinking by means of a removable plug or bulkhead formed of cast-iron segments.

In other shafts, the opening for the tunnel is made by drilling out a hole through the ordinary segments at the required level, and of sufficient size to enable the shield to be passed through.

When the shield has been erected the steel deck is made good, and the air pressure is applied before the removal of the bulkhead plates is started for the commencement of the tunnel.

The opening out for the start of the tunnel has to be carefully done, as there is a liability for air to escape up the skin of the shaft, which might cause a blow at the outset.

TUNNEL UNDER THE RIVER DEE AT CONNAH'S QUAY FOR THE BIRKENHEAD AQUEDUCT.

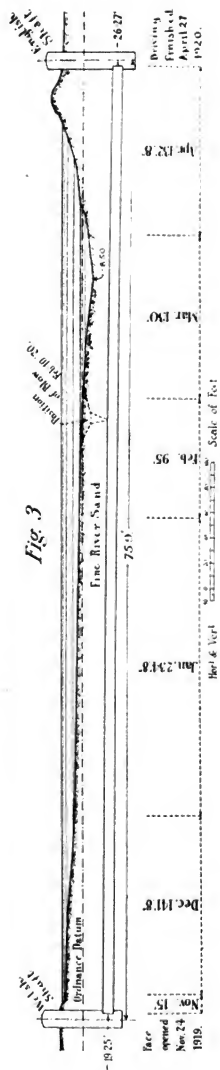
On the course of the Birkenhead Corporation Aqueduct between Cerrig-y-Druidion and Birkenhead, the river Dee has to be crossed. The exact position chosen for the crossing was about five and a half furlongs below the Hawarden swing bridge on the Great Central Railway.

Trial borings, taken on a line within a distance of 100 yards from the actual centre line of the tunnel, showed that the materials in which the tunnel and shafts were to be constructed consisted for the most part of fine sand charged with water. The river at this point is a navigable channel, and in the Birkenhead Corporation Water Act it was laid down that for a length of 100 feet under and across the navigable channel no portion of the aqueduct shall be at a higher level than 10 feet below ordnance datum.

It will be seen from the section, Fig. 3, that the level of the deepest part of the channel is 8 feet 6 inches below ordnance datum and that the top of the tunnel is about 12 feet lower.

GENERAL DESCRIPTION OF WORKS.

The crossing of this river necessitated the sinking of two cast-iron shafts 13 feet internal diameter 759 feet apart from centre to centre, and the driving of a tunnel 8 feet internal diameter between the two



shafts. The tunnel is driven on a gradient of 1 in 107 from the Welsh side of the river towards the English side. The pipes forming the aqueduct at this point are 25 inches internal diameter and the tunnel is designed to take two lines of pipes, one of which has been laid at the present time.

Shafts.—The two shafts are similar in construction and differ only in depth. The shaft on the English side measures 69 feet 3 inches from the top to the cutting edge, and that on the Welsh side 60 feet 9 inches, the actual depth of the cutting edge below the ground surface being 57 feet on the English side and 45 feet on the Welsh side. These shafts are formed of cast-iron segments bolted together to form complete rings, and the depth of the ordinary segment is 3 feet 6 inches. Figs. 4 show ordinary segments, and in Fig. 10 (*v*) is given a detail of the joint, which is the same for both horizontal and vertical joints. It will be seen that all faces are machined, and the joint is made by caulking lead wool into the recess formed for this purpose.

A cast-iron cutting edge was formed of segments 2 feet deep and $1\frac{1}{2}$ inches thick; the remainder of the segments in the shafts were $1\frac{1}{4}$ inches thick with the exception of the portion above ground level, which was built after all the tunnelling had been completed to form a roof and means of access through the tunnel, and which was 1 inch thick.

Tunnel Openings.—Near the bottom of each shaft an eye is formed in the cast-iron segments which was closed by cast-iron bulkhead plates during sinking, shaped so as to preserve the cylindrical form of the shaft, and the tunnel was driven from the eye in the Welsh shaft to the eye in the English shaft.

The diameter of the opening is 9 feet 3 inches, and it forms a sleeve surrounding the first ring of the tunnel. The connection between the tunnel and the shaft is made by means of a cover plate bolted to the flange of the first tunnel ring and a flange on the sleeve, the space between the tunnel and the sleeve being filled with cement grout.

METHOD OF ERECTION AND SINKING.

The methods employed in sinking the two shafts were identical, and it will therefore suffice to describe the sinking of the shaft on the English side of the river, which was the first to be sunk and which is the deeper shaft. As will be seen from the section (Fig. 3), this shaft is on the Dee marshes behind the river embankment; the shaft on the Welsh side being on the foreshore of the river.

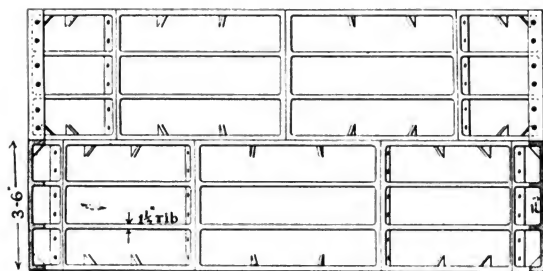
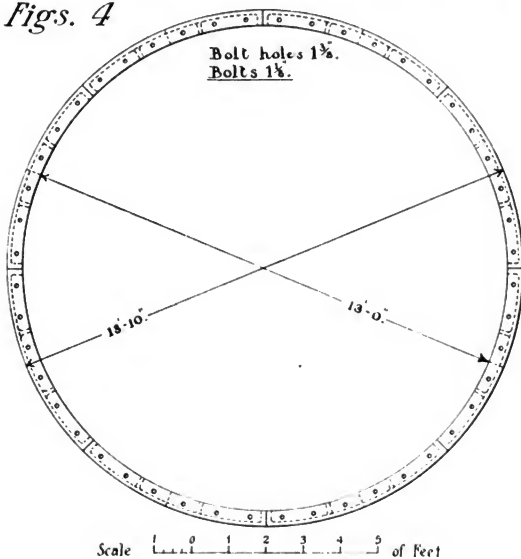
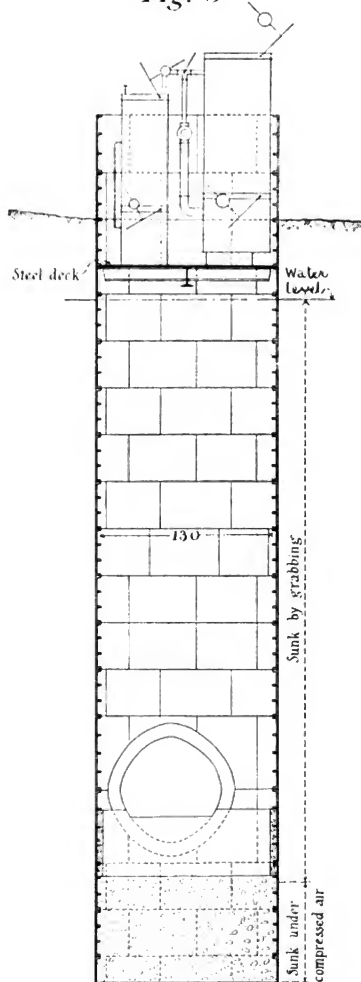
*Figs. 4*

Fig. 5



Scale 1 0 2 4 6 8 10 of Feet

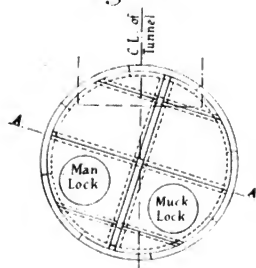
A timbered excavation was taken down to about 6 feet below the surface of the ground to just above the water level. The bottom of the excavation was carefully levelled and the cutting edge was then erected. When this was complete, two rings each 3 feet 6 inches in depth were built on the top of the cutting edge; next followed two rings each 5 feet 6 inches in depth, in which was formed the eye for the tunnel, and, when the bulkhead plates had been fitted in the eye, excavation was started by hand in the bottom of the cylinder.

Sinking by Grab.—The amount of water soon made it impossible to proceed with the excavation in the ordinary way, and grabbing was commenced. The grab used was of $\frac{1}{4}$ -cube yard capacity and it was fitted with four steel tines on each side of the grab.

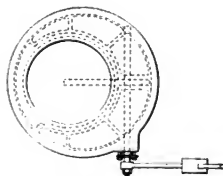
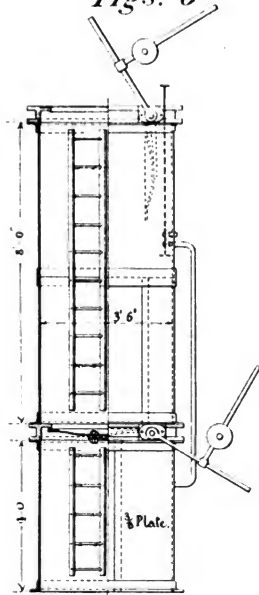
Grabbing was commenced on the 25th April, 1919, and by the 6th June the cutting edge had reached a depth of about 50 feet from the surface. During the operation, kentledge, consisting of steel piles and pig-iron, &c., was added as required.

As the shaft was remote from any buildings and no damage could be caused by settlement, a pump was fixed in the cylinder and it was found that by keeping the level of the water inside the cylinder a few feet lower than the level outside, the bottom was stirred up and it was possible to bring up a grab full on each occasion, and the sinking was considerably expedited. There was, of course, some drawing of the ground around the cylinder, but this was kept filled in with the sand which was excavated.

Fig. 5a



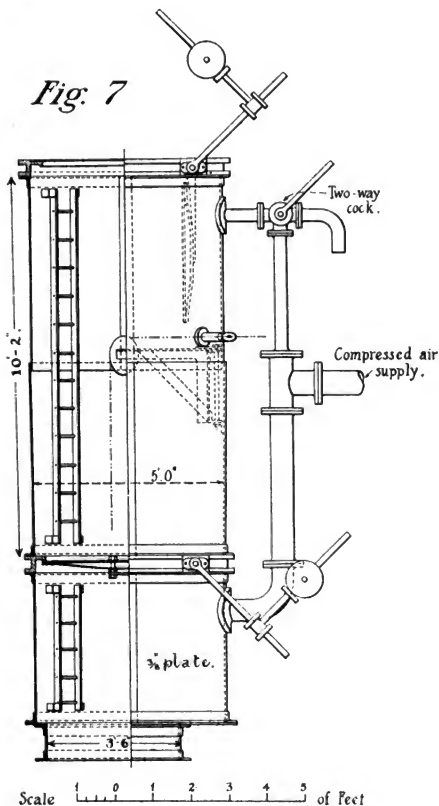
Scale $\frac{1}{4}$ of Feet

Figs. 6

Scale 0 1 2 3 of Feet

When the cutting edge was 50 feet below the surface of the ground, there remained about 7 feet 6 inches to complete the sinking of the cylinder to its final depth, and it was decided to do this portion under compressed air.

Fig. 7



Airtight Deck.—A steel deck was therefore erected near the top of the shaft; the deck consisted of $\frac{1}{2}$ -inch steel plates attached to a $\frac{5}{8}$ -inch steel stringer ring 9 inches wide, bolted between the flanges of adjacent

rings, and the deck was stiffened by means of steel girders. Immediately on top of this deck, two vertical air locks were attached, one lock being used as a man lock and the other as a muck lock. Figs. 5 and 5 (A) show section of the shaft and plan of the steel deck with air locks in position.

Air Locks.—Details of these locks are given in Figures 6 and 7. The air pressure in the man lock can be controlled both from the outside and from the inside of the lock, and the doors are opened by a lock-keeper from the outside. To pass through the man lock, on descending the ladder, the upper door is closed by the lock-keeper and the person inside is then enabled to admit the air pressure by means of the tap inside the lock to suit his own convenience. As soon as the air pressure in the lock is equal to the pressure in the shaft, the person in the lock signals to the lock-keeper by tapping, and the lower door is opened. Four or five men could pass through the man lock at one time.

The muck lock is controlled entirely from the outside and, as will be seen from the drawing, Fig. 7, it is necessary to employ both a crane and a winch for winding material in and out. The method of working is as follows :—

Assume a skip of muck ready for lifting, the bond from the winch is attached to the skip and signal is given by means of an air whistle to the winch driver to wind up. As soon as he has wound up the skip into the lock, the lower door is closed, and the air is blown off by the lock-keeper. When the air has been exhausted the top door is opened and the bond of the crane is lowered into the lock. The hanger-on descends into the lock and attaches the bond of the crane which takes the weight, and the bond of the winch is removed. The crane arm in the lock is swung aside and the skip is then lifted out of the lock.

SINKING UNDER COMPRESSED AIR.

A considerable delay occurred between the time when grabbing was completed and the commencing to sink under compressed air, due to difficulties and delay in obtaining materials. However, by the 10th July, the deck and air locks had been fixed in position and the air compressors had been started. Kentledge was added at the top of the cylinder, which together with the weight of the cylinder and air locks, &c., amounted to about 180 tons. The water was then gradually lowered and the caulking of the joints of the cylinder was done as the water was lowered, the pressure of air being increased to correspond with the level of the water. When the caulking was com-

pleted, the cylinder was again filled with water on account of the August holidays intervening. Work was restarted on the 6th August, 1919, and the water was again pumped down and the sinking under compressed air was proceeded with. When the cylinder was within a few inches of its final level, a valve on one of the compressors broke, and it was again necessary to flood the cylinder while repairs were effected. However, by the 20th August, the sinking and concreting were completed, and on the 21st the shaft was once again filled with water and the concrete was allowed to set under water.

The method adopted for sinking under compressed air was as follows:—The excavation was taken out to a depth of about one foot below the cutting edge over the area of the bottom of the cylinder, leaving a benching one foot wide around the outside, the air pressure being maintained at such a level that the bottom was always dry while excavation was proceeding. The weight of the shaft and kentledge was not sufficient to cause sinking of the cylinder with the air pressure balancing the column of water outside, and in order to start the downward movement it was therefore necessary to lower the air pressure. This was done during a meal hour when possible, and by lowering the pressure some six or seven pounds, the cylinder sunk a depth of about 18 inches in ten minutes or a quarter of an hour. A certain amount of drawing of the ground around the shaft was caused by so doing, but owing to the position of the shaft, this was of no account. No very great difficulty was experienced in keeping the shafts approximately level, and any tendency to deviate was corrected by altering the position of the kentledge. No chains or cables were used during the sinking of the shaft, as it was found that by keeping the compressors running and having air in the receiver which could be quickly released into the cylinder, the sinking could be almost instantaneously arrested, and both shafts were brought to their final level by this means.

It will be seen that, contrary to usual practice, the steel deck and air locks were fixed near the top of the cylinders, and compressed air was put on when the air-tight deck was slightly above the ground level. The whole of the kentledge was also applied at the top of the cylinder, but the success achieved in sinking fully justified the procedure adopted. The maximum air pressure required at the bottom of the English shaft amounted to 23 lb. per square inch.

As already stated, the cylinder on the English side of the river was sunk first, and in order to avoid the necessity of having a double set of air locks, when this shaft was completed the air locks were removed and were transferred to the Welsh side, and the openings through the

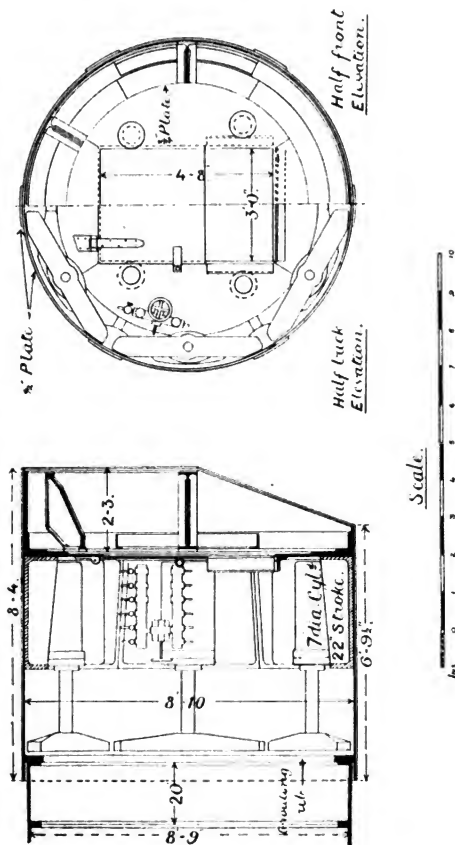
deck were closed by steel plates. The sinking of the cylinder on the Welsh side of the river was done in an exactly similar manner to that on the English side, but the work under compressed air was more easily done as the larger compressors which were to be used for the tunnelling were then available, while on the English side of the river the high pressure compressors only were used in order to avoid the expense of erecting heavy machinery on an inaccessible site, merely for sinking the cylinder.

River Dee.—The river at the site of the tunnel is tidal, the water level varying from about four feet above datum at low water to sixteen feet at high water of spring tides. The tide rises suddenly in the form of a bore at the spring tides, passing up the river at about eight knots, and high water is attained approximately one hour after the bore has passed. Low water occurs some four hours after high water, the tide ebbing at the rate of about twelve knots. The rise and fall of the tide is irregular and depends upon the direction and force of the prevailing winds.

Pressure Regulation.—Before starting the tunnelling, a tide gauge, which was marked in feet above ordnance datum, was erected, and this was illuminated at night. During the time when tunnelling was proceeding, the gauge was observed at frequent intervals of the low water period; during the rising tide readings of the gauge were taken about every three minutes, and during the ebb, readings were taken about every ten minutes. A board was fixed in the engine house having parallel columns of figures, the one giving the level of the tide in feet above ordnance datum, and the other the pressure required to balance the hydrostatic head calculated to a depth of two feet below the axis of the shield. A sliding indicator was attached to the board, which could be fixed in any desired position to correspond with the height of the tide. The tide gauge was read by boys who were trained for the purpose, and they immediately proceeded to the engine house and altered the indicator whenever necessary. The engine drivers had to maintain the air pressure strictly in accordance with the figures shown by the indicator, but the foreman in the tunnel was permitted, if necessary, to give instructions to increase the pressure to a maximum amount of 1 lb. above the indicated pressures. The maintenance of the air pressure at the proper level is a very important point, as any excess pressure would be very likely to cause a blow at the face. If the pressure fell below the required amount, water would immediately appear in the invert of the tunnel. An adjustable safety valve was fixed on the main air pipe in the engine house, to ensure that the pres-

sure did not exceed a predetermined amount, and a barograph was used to record the pressures that had been maintained in the tunnel throughout the 24 hours, and records were changed daily.

Fig. 8.



When the tunnelling was started, it was found that there was a lag of about one hour in the tidal effect upon required pressures in the

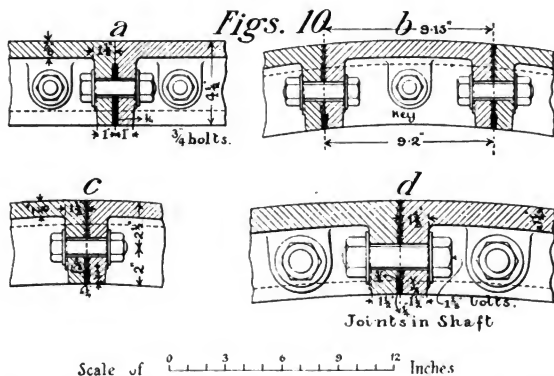
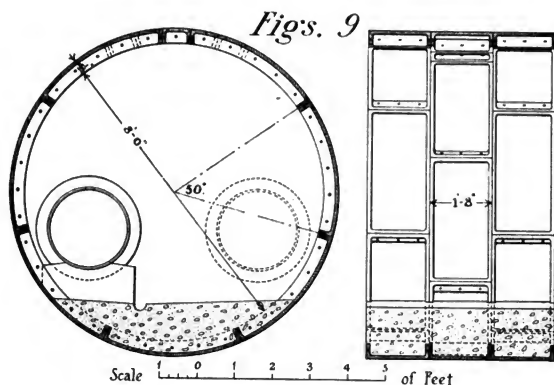
tunnel, and the indicator in the engine room had to be altered to allow for this. The lag gradually decreased as the tunnel advanced and it did not exist while passing under the channel.

Shield.—It was known that the strata to be dealt with throughout the tunnel consisted of very fine sand charged with water directly beneath the tidal river under a head of about 42 feet at high water, and the hooded shield was therefore adopted as the best form of shield for carrying out this work. The details of this shield are shown in Fig. 8, from which it will be seen that the cutting edge at the top extends 1 foot 6½ inches beyond the cutting edge at the lowest point of the invert. This forms a projecting hood or chamber in which the miners can work in safety, and it enables the material to be entirely removed from the lowest part of the invert, so that the shield can advance easily, and there is no danger of the cutting edge being deformed by contact with boulders or other obstructions which might be met with in the course of the tunnelling.

The diaphragm is formed of ¾-inch steel plate with an opening 4 feet 8 inches by 3 feet, the upper portion of which is closed by a steel door and the lower portion by planks fitting in grooves; there are also four holes 6 inches in diameter through the diaphragm clear of the opening, to enable tubular struts to be used to support the face when shoving with the shield entirely closed. The shield is pushed forward by means of six hydraulic rams 7 inches diameter and 22 inches stroke; the pressure being supplied by an hydraulic pump working in the tunnel connected to the shield and driven by high pressure air.

Iron Lining.—The tunnel, which is 8 feet internal diameter, is built up of cast-iron segments 20 inches wide, seven segments and one key forming a complete ring. The metal skin is ⅞-inch thick and there are 36 bolts at each circumferential joint. The key segment is 9·15 inches wide outside and 9·2 inches inside. Of the seven ordinary segments, five have radial flanges at both ends and the remaining two have a radial flange at one end and the other flange set at an angle to meet the tapered flanges of the short key segment. The cast-iron lining weighs 1·869 tons per lineal yard, and each ordinary segment weighs slightly less than 3 cwt., so that they can easily be erected by hand. Details are given in Figs. 9 and 10A, B and C. The longitudinal joints only were machined and the recess provided was caulked with lead. Soft wood packings were inserted in the circumferential joints as the segments were erected, and these were afterwards cut out and the joint caulked with one strand of ⅜-inch lead wire and finished with

rust cement; the latter is made from iron filings with sal-ammoniac mixed in the proportion of about 4 oz. of sal-ammoniac to 100 lb. of iron filings. Grummets made from hemp soaked in red lead and oil were placed under the head and nut of every bolt. The rings of the tunnel



are made to break joint, the key being staggered two holes right and left of the central position; the three positions of the key are shown in the detail (Fig. 9), and every alternate ring has the key in the central

position. The breaking joint helps to maintain the cylindrical form of the tunnel, and it is an advantage from the point of view of strength. With a central key throughout it is sometimes found that there is a difficulty in keeping the iron truly circular.

Tunnelling.—The clay pocketing system was adopted throughout the tunnelling. In this system, pockets 22 inches in length are scraped out ahead of the cutting edge of the shield, the top of the hole being about two inches above the level of the cutting edge of the hood. In open material, the pockets are usually 12 to 15 inches wide, but in the sand which was met with in this tunnel, it was possible to make them considerably wider. As soon as the hole had been excavated, it was at once filled in with tempered clay; another hole was then formed on one side of the first hole and clayed up in a similar manner, and so on, until the ring of tempered clay had been formed three parts of the way round the circumference. When the shield is pumped forward the cutting edge of the hood enters the clay pocket and a skin of clay is left over the top of the shield. This clay remains in position as the shield advances, and prevents the escape of air at the tail of the shield; the compressed air supports the clay until the grout is put in, and no disturbance of the ground above is caused through settlement. The shield for the tunnel having been built in the bottom of the Welsh shaft, tunnelling was begun on the 24th November, 1919. The cast-iron bulkhead plates were removed one by one and clay pockets were formed as the opening out proceeded. Temporary rings were built inside the tail of the shield, which were strutted to the side of the shaft and the shield was shoved forward in the ordinary way by using the temporary rings to push against. The face was kept close timbered and no difficulty was experienced in starting the shield on its journey. As soon as the shield was well clear of the shaft, it was possible to remove the temporary rings and go ahead in the ordinary way, and the method of procedure will now be briefly described.

Assuming that the shield has been advanced and a ring of iron has been erected under cover of the tail, the first operation is the setting forward of the timber supporting the vertical face. Fig. 11 shows the method of timbering the face, from which it will be seen that horizontal planks, shaped to the size of the tunnel, were used. Two miners working side by side in front of the diaphragm commence at the top of the face and remove the first two or three planks. The sand is then excavated, and the face set back for the required distance of 20 inches and the planks are replaced, and chogged from the diaphragm. It was found that the very fine sand in which the tunnel

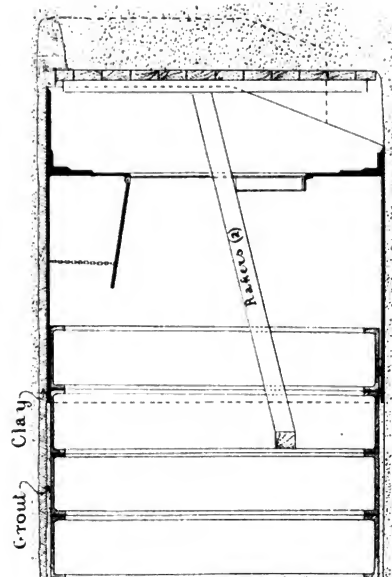
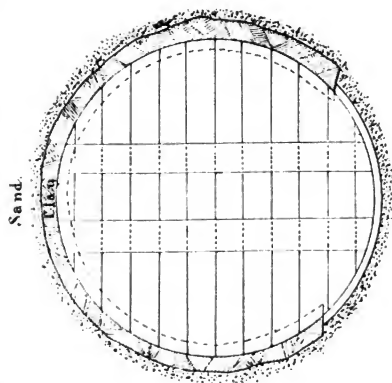
was constructed presented considerable resistance to the passage of air, and as very little escaped it was not necessary to use clay for pugging the face. The setting back of the face was continued, taking out two planks at a time down to the axis level, and at this stage the clay pocketing was commenced. When this had been completed to axis level, the remainder of the face was set back and the clay pockets were formed down to the level indicated. Before the shield could be shoved, the timbering in the face had to be caught by soldiers and strutted either by raking timber struts through the opening in the diaphragm (Fig. 11), as was done in the early stages, or by tubular struts (Fig. 12) through the holes formed in the diaphragm, when it was necessary to shove the shield with the diaphragm closed while passing under the bed of the river. As soon as the soldiers and struts were in position, the shield was shoved forward for the necessary length to enable the next ring to be erected in the tail. By the advance of the tail of the shield a cavity is left around the previous ring erected, and it is necessary to grout this up before erecting the ring for which the shield has been shoved. The rams are slightly withdrawn and grouting ribs are placed in position, as indicated in Fig. 8, and the rams are again advanced so as to hold them in position. The grouting ribs are of oak or elm 2 inches thick, shaped to the inner diameter of the skin of the shield, with a key piece, and pieces of old bags are usually put in behind the ribs in the space between the cast-iron segments and the skin of the shield, in order to retain the grout.

Neat lias lime was used for the grouting in the Dee Tunnel, and it was mixed with water in the ordinary Greathead grouting pan. This consists of a closed cylinder having revolving fins for mixing, and the grout is forced out through a hose and grouting "gun" by air at a pressure of about 80 lb. per square inch. Grout holes are provided in every segment, and after the grouting has been done, screw plugs are inserted in the holes.

While the grouting was proceeding, the miners were at work in the face chogging the timber from the diaphragm, and when this had been done, the struts and soldiers were removed. The rams were then withdrawn and the grouting ribs removed, and the next ring of iron was erected. The erection of the cast-iron lining is quite a feature in this class of tunnelling, and with a gang of men who are used to the work a complete ring can be erected and all bolts tightened in 20 to 30 minutes.

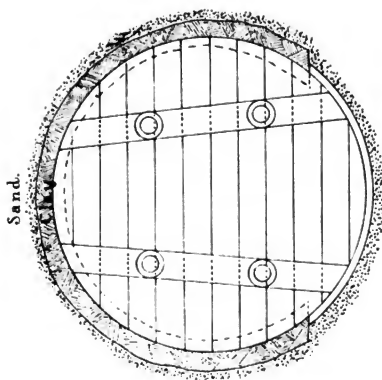
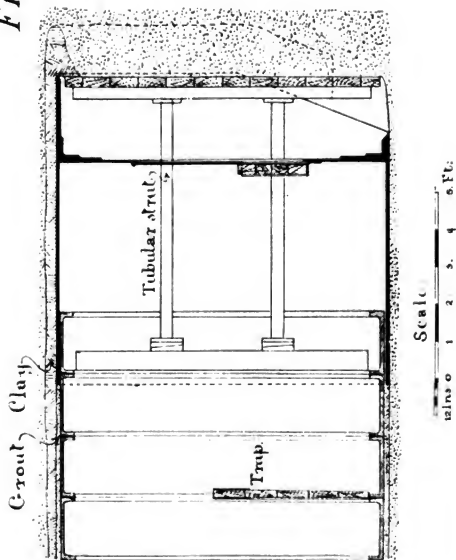
When shoving the shield, it was generally found that it was only necessary to use the four lower rams, and by doing so, any tendency

Figs. 11.



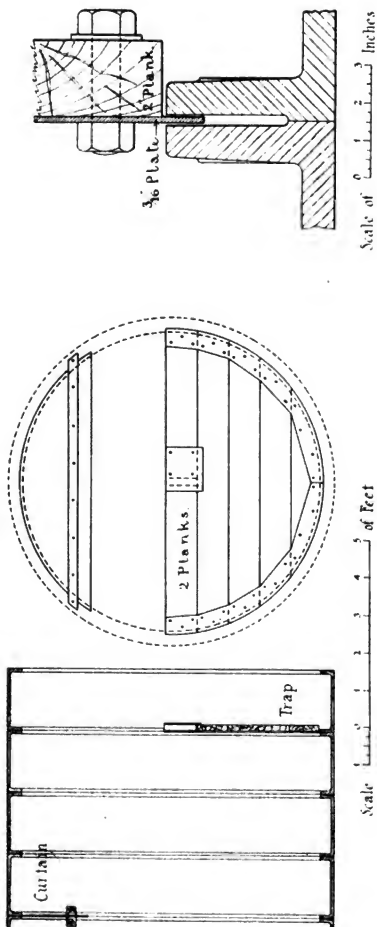
Scale: 0. 1. 2. 3. 4. 5 Ft.

Figs 12.



of the shield to dive downwards was avoided. The pressure in the rams required to pump the shield forward was normally about 1,500 lb. per square inch in the four rams, which gives a total thrust on the shield of about 103 tons. The air pressure was generally increased by half a pound just before shoving, to insure that the invert was perfectly dry, and no difficulty was experienced in keeping the shield true to level. At one period during its journey, there was a tendency of the shield to roll, but this was corrected by the fitting of a plough to the cutting edge and the shield was very soon brought back to its proper position. The rolling of a shield is generally due to the axis of the rams not being absolutely parallel to the axis of the shield, but in all modern shields this point has been carefully attended to, and usually no great difficulties occur from this cause.

Safety Appliances.—The trap which was fitted on the Mersey tunnel shield has already been referred to, and this device has been used in several tunnels constructed during recent years. In a tunnel 8 feet in diameter, a trap fitted to the shield would considerably increase the cost of the shield, and at the same time it would cause an additional obstruction in the face, where working room is already somewhat restricted and consequently progress would be retarded. In all works of this description it is desirable to have as little machinery and obstruction in the shield as possible. In place of the fixed trap a movable trap was therefore used, which was fitted in the tunnel about three rings back from the working face, and this was moved forward whenever the tunnel had advanced three rings. As will be seen from the details shown in Fig. 13, the trap was formed of 2-inch planks fitted with a wrought iron plate, which fitted into the circumferential joint between two adjacent rings. The top plank was at a level 8 inches above the bottom of the steel door which closes the upper part of the diaphragm, and the seal is formed between the diaphragm in the shield and the timber trap bulkhead in the tunnel. Provided the door in the diaphragm is closed, in the event of a "blow," the water would fill up the space between the trap bulkhead and the diaphragm, but as long as the pressure in the tunnel was maintained corresponding to the column of water outside, no serious flooding could occur. In addition to the timber bulkhead, a small curtain was also maintained in the roof of the tunnel, and this was also moved forward from time to time as the tunnel advanced. A telephone was installed from the engine house to the face of the tunnel and a speaking tube was fitted from the bottom of the shaft to the lock-keeper outside. Signals for hoisting and lowering were arranged by means of an air whistle fitted on the top of the deck.

Figs. 13

Progress.—The working week started at 10 p.m. on Sunday night and finished at mid-day on Saturday, and was divided into ten shifts of twelve hours and two of six hours each; there were two intervals of one hour each for meals in each twelve-hour shift. Once the tunnel was started excellent progress was maintained for several weeks and the shield was also shoved forward for the full 20 inches with the door in the diaphragm opened. It was always realised that there was a possibility of a “blow,” but as the tunnel was being driven on a downward grade, it was decided to take the risk rather than introduce restrictions which would very materially reduce the rate of progress and increase the cost. For several weeks previous to the 10th February, 1920, the progress averaged 33 rings per week, equal to a length of 55 feet, but on that date, when the shield had just started to be shoved for ring No. 279, a “blow” occurred in the face and the tunnel was partially flooded. The raking struts supporting the face were in position through the opening in the diaphragm, and the door was hanging open on the suspension chain. When the “blow” occurred, the air pressure in the tunnel was 15 lb. per square inch, and it immediately dropped to 9 lb. One of the miners standing on the platform in front of the shield was carried by the first rush of air through the diaphragm and upwards into the hole. He was, however, dragged out by the foreman in charge and with the exception of being bruised about the face and neck, where he had grazed the cutting edge of the shield, he suffered no serious injuries. The whole of the men working in the tunnel were able to make their way to the shaft in perfect safety. The water rose in the tunnel to the level of the top of the opening in the diaphragm, and a considerable volume of sand also found its way into the tunnel near the face. Soundings were taken in the river over the site of the “blow,” and it was found that a crater had been formed measuring about 12 feet diameter and 4 feet 6 inches deep. This hole was filled with clay and then the water in the tunnel was carried to the surface by means of the “snore” pipe, and the sand was removed. As soon as the sand had been removed up to the diaphragm of the shield, the door was closed and the rams and shield pump and all connections were overhauled before starting work again. The actual work of filling in the crater in the river and removing the sand from the tunnel occupied less than a week, but a further delay of two days occurred owing to the unreasonable demands being made by the miners, which had to be settled before they returned to work. Work was resumed on the 19th February, and it was decided that until the channel of the river had been passed, the diaphragm of the

shield should be closed while shoving. Tubular struts were therefore used, passing through the holes previously mentioned in place of the raking struts already described (Fig. 12). For additional safety, the length of the excavation was reduced so that the vertical face was always kept well inside the hood of the shield, and two shoves were made for each ring of iron. This procedure was carried on for 133 rings and the progress during this time averaged just over 16 rings per week. For the remaining 37 rings the method of shoving for the full length of one ring at a time was adopted and the cutting edge of the shield reached the shaft on the English side of the river on the 27th April. The shaft at this time was standing full of water and by drilling two holes through the bulkhead plates the water was drawn out of the shaft into the tunnel and passed to the surface through the "snore" pipes. When this had been done the bulkhead plates were removed and the shield was shoved forward into the shaft, the rings in the tunnel being built as it advanced. The shield was then dismantled and the cleaning out of the tunnel was proceeded with. By the 14th June, the caulking of the joints and grummeting of the bolts had been completed, and the air was finally released from the tunnel on that date.

Air Locks, &c.—During the whole of the driving of the tunnel, the vertical air locks which had been erected for the sinking of the cylinders were used. In driving, it is usual after a length of about 100 to 150 feet of tunnel has been constructed to build in a horizontal air lock, and in this case, the doors for a horizontal lock were hung in the shaft before tunnelling was commenced, in order that the horizontal lock might be constructed in the tunnel, if found necessary. With vertical air locks the rate of progress is dependent upon the number of skips of material which can be passed through the lock. Half-yard skips with false bottoms were used, and only one of these could be passed through the lock at one time. It was found, however, that it was possible to pass five and sometimes six skips through the locks per hour, and as the excavation only amounted to 3·7 cubic yards per ring, this could easily be dealt with through the vertical lock, and it was decided that it was not worth incurring the extra expense of building a horizontal lock. The objection to a vertical lock for tunnelling, apart from the impossibility of getting more than one skip through at a time, is that both a crane driver and a winch driver are required for winding material in and out, but the additional amount of air stored in the shaft is a decided advantage and adds to the safety of the workings in the case of a small tunnel.

In addition to the man lock and muck lock a lock was provided for the purpose of getting rails and pipes into the tunnel. This consisted of a 4-inch cast-iron pipe with a sluice valve bolted to the upper end above the deck, and a hinged door at the lower end. The rail or pipe was lowered into the lock and it was held in position by a screw clamp working in a Tee piece on the 4-inch pipe. The sluice valve at the top being closed, compressed air was admitted through a cock and then the lower door was opened and the clamp released, allowing the pipe or rail to fall through into the shaft. A 3-inch snore pipe was also carried through the deck and extended to the working face of the tunnel. This was used for ventilation, and for snoring out any water which made its way into the tunnel.

In order to transfer the line from the surface into the tunnel, two 4-inch pipes were attached to holes made in the deck on the centre line of the tunnel, and these were provided with caps and blank flanges at the top and bottom. With the cap removed a plumb-bob with a hook on its lower end was hung in each pipe on the correct centre, and after the caps had been replaced the blank flanges on the lower end could be removed and plumb-bobs attached to the hooks on the bobs in the pipes extending to the tunnel level below.

The number of men employed inside the tunnel to form a working gang was as follows: one ganger; two miners; two miners' labourers; three labourers filling in and running out, &c.; and one hanger-on. The men were paid the ordinary day work rates prevailing at the time, plus a bonus for every ring erected over a certain agreed number per week. This method insures that the maximum rate of progress is always maintained.

COMPRESSED AIR SICKNESS.

On first going into compressed air, sensations of pressure and sometimes pain and deafness arise in the ear. They are due to the inequality of pressure on either side of the drum of the ear, and relief can generally be obtained by swallowing or by attempting to expire with the mouth shut and the nose held tight. The Eustachian tube is opened by these means and the pain usually disappears. If the tubes are blocked, due to cold in the head or other causes, there is intense pain, and it is not advisable to attempt compression. When in the compressed air the voice is altered, becoming nasal, and there is a difficulty in whistling. Generally no unpleasant sensations are experienced in the ear during decompression, but crackling noises due to the escape of air from the Eustachian tube may be heard.

Apart from the above, workers in compressed air are liable to suffer from "compressed air sickness," the most usual form of which is generally known as "bends." This causes intense pain usually in the muscles or joints, and in certain circumstances paralysis ensues.

Until fairly recently, compressed air sickness was generally attributed to the effects of carbonic acid under pressure, but this has been proved to be incorrect. It is now fairly well established that the disease is due to nitrogen from the air dissolved in the body under pressure, forming bubbles on decompression and so obstructing the circulation.

During compression the blood passing through the lungs is saturated with nitrogen and this is carried to the tissues. The blood returns to the lungs and is resaturated, and the process is continued until the whole body is saturated. During decompression the process of saturation is reversed, the blood carrying the nitrogen from the tissues to the lungs.

If the rate of decompression is too rapid complete desaturation is not obtained and bubbles of nitrogen are left in the system, which cause the pains and other symptoms of compressed air sickness.

This subject is very fully dealt with, from the medical standpoint, by Dr. Leonard Hill, in a book published by him a few years ago, and the engineer in charge of works must always take necessary precautions to prevent sickness occurring, and be able to deal with cases should they arise. All men before going into compressed air must be medically examined, and they should be re-examined at frequent intervals. From the results of experiments it has been laid down that "really fat men should never be allowed to work in compressed air, and plump men should be excluded from high pressure caissons." Indulgence in alcohol also increases the risk of bubbles forming.

On the Dee tunnel works no cases of sickness due to compressed air occurred; this is due partly to the fact that the pressure seldom exceeded 20 lb. per square inch, and partly to the precautions taken for securing an adequate supply of pure air at a temperature as low as possible, which ensures that the men are working under healthy conditions. The air was drawn into the compressors from a shaft running through the roof of the engine house, and after being compressed it passed through a cooler, round which water circulated. As a result the temperature in the tunnel remained almost constant at about 58 degrees Fahr. near the bottom of the shaft, and 62 degrees Fahr. near the working face. A 3-inch pipe was carried through the tunnel to the working face and ventilation was obtained by discharging air through this pipe whenever necessary.

On works carried out for public bodies it is usual to specify that the volume of air supplied in the tunnel shall amount to 5,000 cubic feet per man per hour, but there is some difference of opinion as to whether this amount is really necessary.

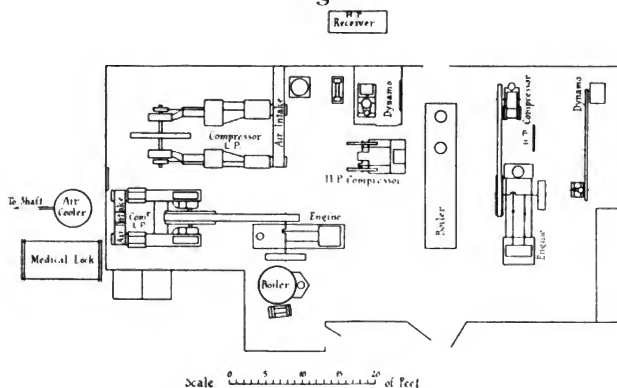
The treatment for men suffering from "bends" is recompression. The patient is put into a "medical lock" and the pressure is quickly raised to a point equal to that under which he has been working, when it will nearly always be found that the pains have disappeared. The pressure is then reduced very slowly, and complete and permanent relief is obtained in almost every instance. In severe cases a second recompression may be necessary.

A medical air lock was provided on the Dee tunnel works formed from an ordinary vertical muck lock placed on its side, but it was never necessary to make use of it. A drying room and mess room were erected adjacent to the working shaft, and hot coffee was provided for the men after leaving their work.

COST OF WORKS.

In round figures the cost of the construction of the two shafts and the tunnel, but not including the cost of laying the pipes, has amounted to about £36,000. The cast-iron lining for the shafts and tunnel cost just over £7,000. The rates of wages and the prices of materials were constantly rising during the construction of the works, and the figures given cannot therefore be taken as a reliable guide to the cost of a similar work at the present time.

Fig. 14



The pre-war price for the construction of the tunnel alone amounted to £58 11s. 3d. per lineal yard, so that the cost of the tunnel 751 feet long would have been £14,660. The sinking and lining of the shafts would have cost about £3,400 at pre-war rates, making a total of, say, £18,000 compared with the figure of £36,000 which the work actually cost.

Payment by results is obtained in tunnelling by the adoption of piecework or bonus work, and the author's experience shows that the labour costs for this class of work have not increased anything like to the same extent as in work where no such system can be adopted. Picked men are usually employed on tunnel works, and the bonus cannot be earned unless the men work steadily.

Plant.—In Fig. 14 is shown a general arrangement of the engine house, from which it will be seen that the whole of the machinery was in duplicate. The works were started at a time when it was extremely difficult to get plant and materials, and the best had to be made of the plant available. Owing to restrictions the coal which had to be used was of very poor quality, and no doubt the cost of the work was increased on this account.

The following plant was used during the construction of the works :—

Compressors—Low Pressure.—Ingersoll-Sargent, steam driven, direct coupled, two cylinders, 20 inches by 18 inches.

Ingersoll-Rand, belt driven, two cylinders, 18 inches by 16 inches.

Compressors—High Pressure.—(80 to 90 lb. per square inch for grouting and driving shield pump.)

Sentinel, two-stage vertical type, belt driven.

Hathorne & Co., "Reliance" horizontal steam driven.

Boilers.—Davey Paxman semi-portable, 40 N.H.P.

Cochran vertical multi-tubular, 30 N.H.P.

Maclaren semi-portable, 30 N.H.P.

Clayton portable, 15 N.H.P.

Economiser.—Gascoyne No. 3.

Electric Plant.—1½ K.W. lighting set, direct coupled, steam driven, 100 volts. Ernest Scott & Mountain.

4 K.W. generator, belt driven, by Ernest Scott & Mountain. Vertical type engine.

Cranes.—Carrick derrick crane.

Grafton 2-ton travelling crane.

Winch.—One steam driven winch for winding into muck lock.

GENERAL REMARKS.

Several small tunnels have been constructed recently, or are in course of construction in various parts of the country, and although they may differ in some respects, the general methods adopted in the construction would probably follow on the lines described for the Dee Tunnel, where they are in water-bearing strata.

Tunnels may now be constructed with certainty of success where they would not have been contemplated some years ago, and the author looks forward to a considerable development in this branch of engineering—both for large and small tunnels—when the financial state of the country permits.

Tube railways have become almost standardised and experience has proved that the very heavy cast-iron lining, such as was adopted on the Vyrnwy Aqueduct Tunnel, is unnecessary. The thickness of metal in the running tunnels of tube railways is usually $\frac{7}{8}$ -inch, and in the river sections it does not exceed 1 inch.

ENGINEERS AND CONTRACTORS.

The Dee tunnel works were designed by Messrs. Sir Alexander Binnie, Son & Deacon, of Westminster, whom the author has to thank for permission to publish details in regard to the work.

Mr. E. S. S. Boyle was agent and engineer for the contractors, Messrs. John Cochrane & Sons, Ltd., of Westminster. Mr. C. H. Webb was their assistant engineer in charge of plant and machinery, and he resided on the site during construction. Great credit is due to the contractors for the very able way in which they carried out the works.

The Dee Tunnel formed a part of contract No. 3 of the Birkenhead Corporation Waterworks, on which the author was Resident Engineer.

In conclusion, the author desires to express his thanks to the President for the facilities he has given him for obtaining information in regard to the Vyrnwy Aqueduct Tunnel.

The Paper was accompanied by numerous plans which are reproduced as illustrations in the text.

DISCUSSION.

The PRESIDENT remarked that they had had a paper by a specialist. Those of them who were fortunate enough last year to visit the tunnelling works under the river Dee, could not fail to have been struck by the excellent organisation and the wonderful drill—he called it a drill because it was highly organised work—carried out by the workmen. The manner in which they put the rings in position was, he thought, an object lesson to most of them. The author had prepared a paper which was probably a good deal more valuable to them than he himself realised. It was all intensely simple to the author, but he could not imagine a type of paper which would be of more use to an engineer who was called upon to carry out work of a similar nature. It was full of practical details. The author had been extremely frank and had told them of his difficulties. To his mind there was very often more to be learned from failures than successes. On that particular job it might be fairly claimed that it had been almost entirely free from failures, but this happy result was due to the skill and knowledge of those responsible for the undertaking. In a very humble sentence they were told that on a certain date the tunnel met the shaft on the Cheshire side. He thought that it was a very fine performance to have hit the opening in the Cheshire shaft exactly as they did. He knew that just before joining up were very anxious moments for the engineer. Without referring any further to the paper he was sure that they would all join in according to the author a very hearty vote of thanks for his paper.

The President

Mr. E. S. S. BOYLE considered that the description of the Dee Tunnel had been so full that little was left to be said on the subject so far as description was concerned. He would just refer to the shafts; the method of sinking was fully described in the paper, but it was not a method he would like to recommend, excepting in the very exceptional circumstances in which those shafts were sunk, viz., in very fine material such as the sand that was found in the Dee Valley and where, out in the open, there was no risk of damage to property. In driving small tunnels in water-bearing strata the pressure was, of course, of the utmost importance, the pressure having to vary exactly with the rise and fall of the tide. At the Dee they had some little difficulty in having an efficient tide gauge. They had to put up posts in the river with large figures on them, but there were circum-

Mr. Boyle

Mr. Boyle stances when much more efficient tide gauges could be fixed. In the case of a tunnel which he drove some years ago, a large float was made use of from which a suitable wire was led to the engine room, the pull of the wire being reversed by being passed through a snatch block attached to a weight, and from the weight a wire led to an indicator showing on a gauge 6 inches to 1 foot rise and fall of tide. Thus it was possible to put a gauge right in front of the engine driver so that he could see exactly the state of the tide at any moment. There was one point that was important in making a float ; he had known tide gauges to be fitted up which would not work simply because the float was not large enough ; they wanted something large and heavy and without any possibility of jamming.

Another point about the sinking of the shafts ; he tried to determine the amount of skin friction ; it was not very easy to do but so far as he was able to judge it was 2 cwt. to the square foot. In some shafts which had been sunk in London, the skin friction was as much as 5 cwt., and in certain cases it had even been higher, 7 or 8 cwt. Needless to say that was a very important factor in sinking shafts. There were some uses which small tunnels of the nature described in the paper were put to, which were not so generally known as tunnels like the Dee and Tube railways and so on. He referred to certain tunnels which had been constructed in recent years for condensing water in connection with large generating stations. With the turbo-generators now almost universally used in large stations, an enormous amount of condensing water was required ; a station generating 50,000 units required something like 72,000,000 gallons a day, and of course the ordinary suction pipes were quite inadequate. On the Thames in recent years three of these tunnels had been driven ; two for the electric generating station of the London County Council Tramways, at Greenwich, and one for the London Electric Railways, at Lotts Road. He had been associated with the Greenwich tunnels and these went straight out into the river, about 400 feet. The first one constructed was of 6 feet internal diameter, with a vertical diaphragm, the water was drawn in on one side of the diaphragm and discharged on the other. The intake and the discharge were formed in the bed of the river by means of shafts sunk in the river. For purposes of construction, these shafts were carried well above maximum high water, the tunnel being driven into the shafts, and when everything was complete the bolts at ground level were taken out and the shafts above the ground level removed. The tunnel for Lotts Road generating station had a horizontal diaphragm. It was

a matter of opinion which was the better, but, perhaps, looking at it from a constructional point of view, he personally rather preferred the vertical diaphragm. Later on, at Greenwich, it was found that one tunnel was not sufficient and a second one was constructed. He had a drawing which showed this second tunnel, which he would send round for inspection. This second tunnel had no diaphragm, and it was now used for drawing in the water—the intake—while the original tunnel was used for discharge. One very important point about this sort of work was the formation of the mouth in the river bed and even more particularly the level of the mouth, if this was not sufficiently below the lowest possible low water a very considerable eddy was formed which, of course, was not only dangerous to any small craft that might be passing, but drove air into the pipes, which had to be avoided at any cost. In driving the tunnels at Greenwich, at the outer end of the first tunnel there was only 6 feet of open ballast between the top of the tunnel and the bed of the river, and of course very great care had to be taken in regulating the pressure, and in clay pocketing. When constructing this tunnel, they laid down a clay blanket on the line of the tunnel. In the second tunnel they did not put down a clay blanket. He knew a great many people were in favour of these clay blankets, they were very expensive, but he did not think with reasonable care that they were really necessary for small tunnels. They did not use a clay blanket of any description in driving the Dee Tunnel.

Mr. Boyle

There was another use to which these small tunnels were put, and that was as pilot tunnels for larger tunnels. He thought that the most notable instance of this was the tunnel driven across the Thames as a pilot tunnel for the Rotherhithe Tunnel, which was 30 feet in diameter. The pilot tunnel served two purposes: it proved the nature of the ground through which the larger tunnel was to be driven and also served the purpose of a top heading during the construction of the larger tunnel. He would close his remarks by thanking the author for the very kind reference he had made to the firm which he himself represented. The author was rather too modest to say that the success of the Dee Tunnel was largely due to the assistance and co-operation in every way of the resident engineer, and he hoped that he might be fortunate enough at some future time to carry out other work under the author's superintendence.

Mr. C. A. NEEDHAM wished to associate himself with the remarks made by the President in regard to the subject of organisation which the author had, with characteristic modesty, omitted from his paper.

Mr. Needham

He thought that it was desirable that all who had had the pleasure

Mr. Needham of visiting the work at the Dee Tunnel should appreciate the fact that the rate of progress which was maintained during the whole of the work was due entirely to the organisation which was designed before any of the work was commenced. It was carried out during a time when supplies of necessary material and machinery were very difficult to obtain, and when it was still more difficult to ensure that regular and continuous supply necessary to maintain an unbroken run of work, which was vital when the standing charges were heavy as in this class of work. He thought that both the resident engineer and the contractors were greatly deserving of compliment for the way in which they managed to get over the difficulties which, he was in a position to know, arose only too frequently.

There were one or two points in the paper upon which he would like to ask for a little further light, although he ventured to say that he had had the advantage of being in touch with this work to a greater extent perhaps than most of those present, other than those who were directly responsible for the work. First, with regard to the sinking of the shaft. If the shaft had commenced to roll or turn during the sinking the limited margin of room in the eye of the shaft, through which the tunnel proper commenced, would have thrown them considerably out of true direction, and would have necessitated special segments to bring them back again to true direction; he did not suggest that anything like that had happened, but it might have been anticipated and prevented through measures which were taken. It would be interesting to know whether that was the case, and, if so, what were the steps taken.

In regard to the air pressure and its regulation, it was stated that the pressure was calculated to balance the head of water at a depth of 2 feet below the axis of the shield. That seemed to him as if indicating that there would usually be water in the tunnel amounting to a depth of 2 feet 5 inches in the invert, which, as they knew, was not the case. He was wondering whether that extra pound of air pressure, which was applicable at the discretion of the foreman, was necessary to be almost continuously utilised in order to ensure a dry invert, otherwise he failed to see how the water was kept out of the workings.

There was another point upon which he would be glad to hear a little further explanation from the author; that was the necessity for entirely closing the shaft before shoving forward when the face of the work was closely timbered and supported by soldiers and tubular struts through the diaphragm on to the tunnel lining.

With regard to the question of progress a reference was made to the "snore" pipe with which they kept not only the air in the tunnel good but by which the water was "snored" out. That he took to be somewhat of an adaptation of the air lift. The pressure of air available in the tunnel was only sufficient to reach the level of the water outside, whereas the shaft from which this water was discharged was no doubt some feet above the river level, and it did not appear to him quite clear how they managed to discharge that large quantity of water on the occasion of the blow when the shaft was high above the level of the river.

Mr. Needham

These were all the remarks he had to make, but he thought that this paper was a very valuable addition indeed to the records of work of this nature.

Professor S. W. PERROTT remarked that he had come to learn something about these tunnelling shields, which were very interesting. There were one or two questions which suggested themselves to him.

Prof. Perrott

One was as to how the centre line was maintained through the tunnel and the verticals carried down the shafts from the surface line. He would be interested to know how accurately the lines in the sections joined up, as the base line transmitted down the shaft must necessarily have been short. The subsequent carrying through of the line must have been quite satisfactory, once the direction was accurately determined, as the tunnel was straight. At the same time it would be of interest to hear from the author how near the tunnel sections came to joining up accurately.

He was very interested in hearing about the clay method of dealing with the excavation of sand to which the President had referred. It certainly appealed to him as a most important means of carrying out such work in this class of material. In fine sand, there must be great risk of a blow out at any moment. It struck him as rather remarkable that the effect of the high tide coming in should lag as much as an hour at that part of the tunnel which was more removed from the centre of the channel, but possibly the material at that point was of a somewhat denser nature than that beneath the centre of the river.

On page 164 the segments were referred to and the key segment was given as 9.15 inches wide outside and 9.2 inches on the inside. He would like to know if that was correct. There were many interesting facts in the paper which helped to clear up his mind on points of uncertainty, and he quite felt, with other members, that it was a very valuable paper to have on their records.

Mr. Dickinson

MR. HAROLD DICKINSON was of opinion that the cost of the Dee Tunnel, as far as he could calculate, worked out at about £150 a yard, and that, he took it, was for an 8-foot diameter tunnel. He would be glad if the author could tell them how that would vary for a tunnel, say, 12 or 13 feet in diameter, and if the cost would be proportional. He would also like to know if the author could tell him if the £36,000 total cost included the shaft and what proportion of that cost the actual tunnel was.

Mr. Boyle had mentioned rather an interesting point in connection with the Greenwich Tunnel. He did not quite follow him; the opening was made in the river when the tunnel was made; he was not quite clear as to the use of the clay blanket. There was just one other point which interested him, and that was as to whether they would have any objection to running electric cables through the tunnel.

Mr. Fargher

MR. T. E. N. FARGHER asked if the author could explain how he transferred the direction lines from the top down the shaft. If it was done before the compressed air was put on, there would then be water in the bottom of the shaft, but after the compressed air was on he would have to get through a steel deck. If the author could describe that, it would be very interesting.

Mr. Miller

MR. H. M. MILLER had four questions which he would like the author to answer. The first was as to where the author said near the bottom of page 148: "It will be seen that the trap was formed by introducing a second diaphragm a few feet back from the main diaphragm, and the horizontal sill of the former was about 6 inches above the level of the opening in the main diaphragm. With this arrangement, provided that the pressure of air in the tunnel did not fall below the pressure of water outside the tunnel, no serious flooding could occur." He wished to know how was it ensured that the pressure should not fall below the other pressure. On page 151, the author said: "A second method is to sink the cylinder by grabbing." He would like the author to say how he ensured that the cylinder sank perpendicularly and if it did go out what method was adopted to straighten it. On page 159, the author said: "When the cutting edge was 50 feet below the surface of the ground, there remained about 7 feet 6 inches to complete the sinking of the cylinder to its final depth, and it was decided to do this portion under compressed air." He wished to ask why the change was made when they got to that depth, and the other question was as to what the author said on page 160: "Assume a skip of muck ready for lifting, the bond from the winch is attached to the skip and signal is given by means of an air whistle to the

“winch driver to wind up.” He would like the author to give them some idea of the time that it occupied between the time that the signal was given for lifting and the time the skip was absolutely lifted out of the lock.

Mr. Miller

Mr. H. A. WHITAKER asked whether, in connection with the Dee Tunnel, any other material had been considered besides cast-iron. He could see that in a smaller tunnel the rate of excavation would be so great that it would be necessary to have a solid backing, so as to be able to push the shield forward, but in a large tunnel it would be possible to have a concrete lining which would set in time and would be sufficiently solid to enable the shield to be pushed forward when the setting had been completed. There was also the question of corrosion in a cast-iron tunnel that perhaps the author might have some information about.

Mr. Whitaker

The PRESIDENT said that possibly some of the members present might have to prepare designs and possibly carry out work in the future similar to that described in the paper, and the present was therefore a golden opportunity to obtain information from the author. There were several points which interested him personally. With regard to the Fiddler's Ferry Tunnel, the very great difficulties encountered in the construction of this tunnel were now a matter of history. It was not mentioned in the paper that actually the first shaft on the Cheshire side had to be abandoned and a second was put down, from which the tunnel was eventually driven. Then again, as showing to what an extent they were groping for the truth in those days, the shafts were of so small a diameter that it was not possible to erect the shield for driving the heading in the shaft. Those members who had seen the tunnel under the Dee would, doubtless, have noticed how large the shafts appeared in proportion to the diameter of the tunnel. He took it that the size of the shaft was governed by the room required for the erection of the shield. In the Fiddler's Ferry Tunnel it was necessary to underpin and enlarge the shaft at the bottom, which, as would be realised, was a difficult and costly operation with the imperfect appliances then available. The shafts of the Mersey Tunnel were lined with complete cylinders, each of the rings being a whole circle, whereas in the case of the Dee Tunnel and the Tube tunnels in London, the rings were built up in segments. Personally, the point that struck him most when he inspected the Dee Tunnel, was the great advance that had been made in driving under compressed air by the use of the clay pocketing system. He believed a large amount of the success that was achieved at the Dee Tunnel was due to the use of

The President

The President clay. No doubt they were extremely fortunate in having, so far as he saw, an ideal material to work in. In front of the shield, one saw a face of dry clean sand which was something one hoped for but very rarely enjoyed, and there was no doubt that they were able to carry on the work with much greater advantage than if they had been in material which retained the water under air pressure and would not become dry. Such material was also liable to frequent changes in quality. Mr. Needham had spoken of the variation in the pressure of the air. He would remark that was one of the most difficult matters to regulate in work of this character. The workmen were always extremely anxious to keep the pressure sufficiently high to keep their feet dry and did not appear to worry about blowing the roof off the tunnel. It was necessary to adjust the pressure between those two extremes, so that there was no risk of a blow at the top of the heading, while at the same time the pressure of water at the invert was balanced. With a large tunnel this was a much more difficult operation than with one of the size described in the paper.

The Author The AUTHOR, replying to the discussion, said that he had to thank the various speakers for the very kind remarks made and the way the paper had been received. He had tried to read a practical paper which would give practical working details that would be of some use to the Members of the Society. With regard to Mr. Boyle's remarks, he quite agreed with what he had said about the shafts. The sinking of shafts by loading and forcing them down into the ground was an expensive method; and if it could be done by underpinning it was far better.

Mr. Boyle had stated that the figure for the skin friction was about 2 cwt. per square foot, and if a deep shaft had to be sunk by loading, it was necessary to add a tremendous weight to force it down. In the Mersey Aqueduct Tunnel he remembered Mr. Deacon saying that on one shaft they had a dead weight of about 1,000 tons. All that dead weight had to be handled more than once and it was very expensive to do so. Regarding the clay blanket, Mr. Boyle and he discussed this matter, and they agreed that the clay blanket in the sand of the River Dee was rather worse than useless. It would cause an obstruction in the river where there was a big scour and it would probably have the effect of shifting the channel from one place to another. If they had open ballast in a larger tunnel, such as they had at Blackwall, he thought that they would have to have a clay blanket but certainly not with a small tunnel in sand. Mr. Boyle had mentioned the three condenser water tunnels on the Thames which

his firm had constructed. There was a similar tunnel now in course of construction on the Forth, and he thought that several of these tunnels would be constructed in the near future. They heard a good deal about the development of large electrical schemes which would require condensing water, and they would doubtless find this the proper way of getting it.

Mr. Needham had mentioned the question of the rolling of the shafts. As a matter of fact one of the shafts did twist a little during sinking, but it was not enough to make any appreciable difference. If a shaft did take it into its head to twist he thought that they were powerless to prevent it, especially in such material as they were going through at the River Dee. In regard to the pressure being calculated to a height of 2 feet below the axis, it was a fact that, except in certain cases, the air pressure in a tunnel was seldom required to be equal to the full hydrostatic head of the water outside. In the Vyrnwy Aqueduct Tunnel, he remembered reading that they worked at about two-thirds of the hydrostatic head, and it just depended upon the material in which the tunnel was being constructed whether the air pressure corresponded to the full hydrostatic head or not. When the tunnel was right under the bed of the River Dee the pressure practically corresponded with the full hydrostatic head, but as the President had explained, if tunnelling was started on the assumption that the air pressure had to be regulated to the pressure corresponding to the head at the invert, there would be of necessity an excess pressure at the roof of the tunnel. It was better to run the risk of having a little water in at the bottom than to have excess pressure which was going to cause a blow at the top. Of course in a tunnel 8 feet in diameter the difference in pressure required to balance the hydrostatic head at the top and the bottom of the tunnel was less than 4 lb. per square inch and this did not really matter very much, but when they came to tunnels over 12 feet in diameter there was a greater difference and it became important. The next point was the object of shoving the shield with the diaphragm closed, although the face was timbered and strutted. The sand looked very nice when the correct pressure was on and when it was quite dry, but if for some reason the pressure fell a pound or two it became a boiling quicksand immediately. No strutting would be any good, as the whole face would collapse, and of course that did happen when the blow occurred. There was a little bit of excess pressure or a weak spot through which the air escaped and immediately the whole of the face collapsed. The snore pipe was nearly always adopted in tunnels for removing water.

The Author Although the air pressure would not force the water out above the top of the shaft if the mouth of the pipe was completely submerged, yet if the mouth was only partially submerged and air was allowed to enter, the water was snored out, and the noise caused gave the pipe its name.

The President had given them further information about the Mersey Aqueduct Tunnel and it was certainly a very interesting and instructive piece of work. It was carried out by two contractors who were feeling their way all the time, and he thought that it was clear from the fact that the Dee Tunnel had been constructed in about 15 months under present conditions, that there had been considerable advances and that they had learned a lot since the Mersey Aqueduct Tunnel. In designing works of this description it was important to bear in mind that the shafts should be sufficiently large to enable the shield to be erected without being cramped for room, and the shafts at the Dee, which were 13 feet in diameter, complied with this requirement. The opening for the eye in the shaft projected inwards a distance of 3 feet, which gave 10 feet in the clear on the centre line, and the longest dimension of the shield used was 8 feet 4 inches. The President had also referred to the clay pocketing system and, in the author's opinion, that system, which was introduced by Mr. Dalrymple Hay, had done more for tunnelling in water-bearing strata than anything else. The work, which was carried out on the South London Railway by Mr. Greathead, was pioneer work, and he was, more or less, feeling his way. The Greathead shield was well adapted for tunnelling in clay, but it was not much use in water-bearing strata. They had to timber a length in advance of the shield and then shove the shield into it. Mr. Hay said that was not a proper method of tunnelling and he set to work and devised this system of clay pocketing with the hooded shield. The sand, as the President had said, was ideal, but only when the pressure was just right. It was a uniform material and not much air escaped through it, but if a tunnel had to be driven through variable strata such as was met with in the Mersey Aqueduct Tunnel, it would be made uniform by pugging the face. If veins of open ballast were encountered where a lot of air was escaping, it would be necessary to clay the face. It was very easily done and the same result would be obtained as they had in the Dee Tunnel, but it meant a little more work. Of course difficulties arose when they had silt, mud and stuff which was wet and could not be dried by means of compressed air. In the Hudson Tunnel, on one occasion, they dried the silt by means of heat, using flares or blow pipes. This led

to the story that the Americans in building their tunnel, when they met clay, took lamps down and baked the clay, which they used as bricks after it had been baked, but he would not like to say that this was actually the case. While on the subject of the Hudson Tunnel, he might mention that this was a case where the tunnel was partly through silt, practically river mud, which was about the worst material for tunnelling in, and in that case they did very little excavation, and sometimes none at all. They simply shoved the shield right through the silt, displacing it, and it found its way upwards into the bed of the river. He did not know that the river authorities in this country would allow this to be done, even if it was possible, but there were only exceptional cases where this method could be adopted.

Professor Perrott and Mr. Fargher had both referred to the lines through the tunnel. The lines had to be got down two or three times after the air was on, and the method of transferring the lines was briefly referred to in the paper. They could not, of course, put a hole through the deck and hang their lines down because the air would escape, and a method which Mr. Boyle had used on the Greenwich tunnel was adopted. On the top of the deck were bolted two 4-inch cast-iron pipes, provided with caps. Below the deck there were short extensions with blank flanges. A bridge piece was fixed in the top of the pipe, and when the theodolite had been set up on the centre line, wires attached to the bridge were sighted in. Each wire had a plumb-bob with a hook on the end, which hung in the pipes reaching to within an inch of the blank flange at the bottom. When satisfied that the lines were correct, the caps were replaced on the pipes and the blank flanges were removed below the deck. Plumb-bobs were then attached to the hooks extending to the level of the tunnel below.

The setting out of the River Dee Tunnel was an easy bit of setting out, because it was on a straight line and it was possible to see across the river. Setting out was work that must be done very carefully, and of course the slightest mistake would cause trouble. If there were curves in a tunnel, the theodolite was set up on the intersection point if it was within the tunnel, but if not, it was necessary to come round with chords or tangents. Setting out of tunnels was simply a matter of very careful theodolite work. The Dee Tunnel came through well, it was certainly within $\frac{1}{8}$ -inch both for line and level when the shield reached the opposite side of the river. With regard to the lag, he did not know that he could say anything; there was a lag of one hour. Why it was about an hour he could not say. The strata throughout

The Author was sand of a uniform nature, and looking at the section (Fig. 3), it might be expected that there would be a certain amount of lag at the start of the tunnel. At any rate, whether it was expected or not, the lag did exist but it gradually diminished as the tunnel advanced under the bed of the river, and the effect of the bore and the rising tide was felt at once. Professor Perrott had also asked about the dimension of the key segment. This was quite correct; the key segment had tapered instead of radial joints for the purpose of getting it into its place. Sometimes the key segments were made the same width at the top and bottom.

Replying to Mr. Dickinson, he might state that in pre-war days an 8-foot tunnel in free air would have cost about £25 per yard, and a 12-foot tunnel about £45, and those figures might be taken as some guide to comparative costs of tunnels of such sizes. He could not, without referring to costs, tell him exactly how much of the £36,000 represented tunnel cost. He had mentioned in the paper that it was necessary to be very careful in comparing costs, and nowadays costs were not very much use to anybody unless they knew the whole circumstances. Prices were varying so much during the construction of the work, and some of the iron had been bought at pre-war rates and some at much higher rates, that it was very difficult to arrive at any reliable unit costs. With regard to the electric cables, curiously enough there were electric cables through the Dee Tunnel. The cables were placed there by Messrs. Summers, under agreement with the Birkenhead Corporation, and they were to convey current from Messrs. Summers' works to a colliery at Buckley, which they had recently purchased. These cables were armoured cables, which it would be possible to lay in the bed of the river, but it was more handy to lay them through the tunnel, and he believed that the voltage was 11,000 volts. They were supported by hangers in the tunnel.

Mr. Miller had referred to the trap. He thought that if Mr. Miller would think it out, he would see that it was an effective way of stopping a blow, but it could not be effective unless the pressure was maintained. In the event of a blow occurring, water would immediately start to come in, and it would fill the trap and prevent further escape of air and so stop the blow. As long as the compressors were kept running and the trap was maintained perfect safety was ensured, but if anything happened to the compressors and they stopped, nothing could prevent complete flooding of the workings.

Mr. Miller had asked how they kept the cylinders right when grabbing. By carefully watching and shifting the weight on the

cylinders whenever they started to get out of level, it was possible to keep them practically vertical. In one case strutting the shaft had been tried, but he did not advise it, if it could be done by moving the weight, which was the best way. Mr. Miller had also asked the reason for finishing the sinking under compressed air. The bottom of the shaft had to be sealed and this could not be done successfully under water. Of course if the shafts were being sunk by underpinning, considerably more than 7 feet 6 inches would be done under compressed air, but the shafts went down so very well by grabbing that it was decided to continue to the depth shown. Another question was as to the actual time from the signal given to wind up to the time the skip was out of the lock. That would probably be three to four minutes, for they had to wind the skip into the lock, exhaust the air from the lock, open out and hang on the crane bond. Mr. Whitaker had asked about alternative lining in a tunnel. Of course it was well known that tunnels were being constructed in brick, and concrete segments were being used, but in loose water-bearing strata under a head of water there was nothing else practical except the cast-iron lining. In regard to corrosion, he did not think anybody knew what the life of these tunnels was. The President would tell them that the Vyrnwy Aqueduct Tunnel, which was quite good, had been in use 30 years or more. The City and South London works were just as good as they were 30 years ago. He did not see why the life of these tunnels should not be almost indefinite. He would just like to say, in conclusion, that tunnelling, especially in water-bearing strata, was always attended with risk, and it was necessary to know exactly how much risk could be taken. That was practically the secret of success in tunnelling. The engineer in charge of works had to make up his mind how far he could go and stick to it. Tunnelling was a job for an expert, and the more he knew about it the better results he would get when he started to carry out work.

16th February, 1921.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,

President, in the Chair.

The Council reported that the following elections had been made:—
JOHN WILLIAM ASTLEY and RICHARD CRAWFORD REYNOLDS, as *Members* ;
DENIS WILLIAM ALDRIDGE as *Associate Member*.

“Urban Passenger Transport by Train.”

By A. P. ROSS, M. Inst. C.E.

THE subject of this paper is without doubt one of great interest to all classes of the community, inasmuch as the satisfactory solution of the many problems it involves is, at the present time, a matter of absorbing and general importance.

In the conditions of modern life to-day, passengers in large and ever increasing numbers have to be dealt with, and to carry them the use of an elastic and comprehensive plan is imperative.

Special prominence and importance have recently been given to this matter in consequence of the number of Housing Schemes adopted by Municipal Authorities, because, in determining their building sites, they naturally and indeed must look for a ready means of conveying the future occupants of the houses to be erected, to and from their work in the nearest city or town.

In treating this subject from the point of view of a Railway Engineer it is at times somewhat difficult to recognise the dividing line between the respective duties of the Engineer and the Traffic Manager. An endeavour, however, is made in this paper to confine the suggestions as much as possible to the general conditions and problems which properly fall to the engineer to deal with.

The popularity attained by electric traction and motor vehicles has produced a great demand for travelling facilities. The permanent way and bridges of the suburban railways were fortunately able to stand the strain of this additional demand, but the construction of the roads is such as to cause considerable apprehension in the minds of the

Authorities, and indeed many of the roads to-day are full of "pot holes," due to extra traffic and the varying weights and sizes of vehicles running on them, for which they were not designed.

To meet this ever increasing demand for urban traffic there would appear to be three methods for the general use of the community—railways, motor bus, and tramways.

It may be of interest at the outset to follow generally the idea that would appear to have been in the minds of the railway pioneers in respect to the original layout and geographical direction of the main line tracks, tracing from period to period the various developments of local lines constructed for the purpose of meeting the requirements of Urban Passenger Transport, and afterwards to deal briefly with a few details essential to expeditious transit.

A careful and detailed study of Urban Passenger traffic has led the author to the conclusion that the leading factors for its success are :—

- (1) The provision of means for the transit of the largest possible number of people in a single movement.
- (2) Direct rail connection where possible, with interchange points for the rapid distribution of passengers.
- (3) An expeditious method of dealing with them on their arrival at terminal.
- (4) The provision of connecting lines running from the heart of a city or town to the rural districts adjacent.
- (5) Frequent, quick, and cheap transit.

A few diagrams which the author has prepared may help to illustrate generally those ideas, the carrying out of which to a large extent devolves upon the engineer. In designing the track of main or trunk lines, the original scheme of the first railways apparently was to run them straight into the city or town and terminate with a station (Fig. 1) indicated by the thick black line ending with a block marked "station" but, as the population increased, it became necessary to extend outwards by constructing branch or belt lines (Fig. 1) shown by the long and short dots, and to connect up as indicated by the circular dots.

This form of railway layout was no doubt adopted to avoid the congested areas and also to make provision for a larger district by having a number of stations on the line accessible to the various suburban districts through which it passed, bearing in mind the necessity for a minimum of interference with the existing public

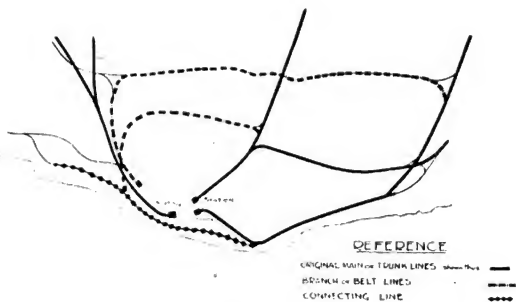


FIG. 1.

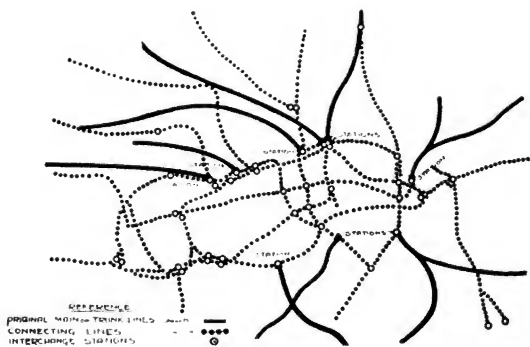


FIG. 2.

highways or streets. Then later, as new areas developed, to provide facilities for the residents, lines connecting up the main and branch lines were laid in. This has been achieved by means of inner connecting lines, as in London (Fig. 2), shown by black dots, chiefly underground, to avoid interference with the street traffic, and having interchange points (Fig. 2) shown by the large black circle, for purposes of distribution.

Except in the case of one or two towns the present suburban services do not touch the heart of the working centre but end at the terminal stations, often some distance away from the office, workshop, or business premises of the traveller. To create an ideal service it would be necessary to connect up this centre with the various railway termini (and this would in all probability mean tunnelling in the cities and towns of to-day) linking up as far as possible all the important points and places, and carefully selecting suitable sites for stations, facilities to passengers for descending into these tunnels, and ascending to the surface, by escalators, lifts, &c., or stairways. In this way, train services could be run out to the rural or suburban districts on the existing metals of railways.

Suburban districts must depend for their growth on the inducements that are offered to the community for travelling to and from business, and in proportion as these are offered the clearing of cities and towns of slum areas and town dwellers becomes more or less practicable. Saving a traveller in time and money must inevitably be a desideratum.

In all large cities and towns a certain proportion of the inhabitants require to arrive at one terminus and depart from another, and moreover, a large volume of interchange parcel traffic takes place between the various termini. At present, in both cases, this involves crossing the town through the streets, while, in the case of a passenger with luggage, a road vehicle is needed, thus adding to the existing congestion. If, however, all termini were connected by a tunnel, as referred to above, and suitable means provided for dealing with passenger, luggage, and parcels, the whole of this additional traffic need not be dealt with on the existing street level, but underground.

So much for a general review of the layout of main lines, &c., with a view to providing for a speedy and convenient method of conveying large sections of the population, who, through urban congestion, have been driven to find homes at some distance from their places of business. The following is an endeavour to deal shortly with the details coming within the sphere of the railway engineer's activities,

taking them under a few headings, such as "Main Lines," "Stations," "Rolling Stock," and "Power."

The "in" and "out" main line roads at terminal stations should be of the greatest possible number to allow of simultaneous arrival and departure of trains, and the layout of the permanent way should be such that trains may arrive and depart from any platform. This can be done by the provision of what are known as scissors crossings at the points where the rails enter or leave the station (Fig. 3), so as to enable the station to be used to its utmost capacity during what are known as "rush hours," or in the case of a derailment by means of what are called slips, double or single (Fig. 3).

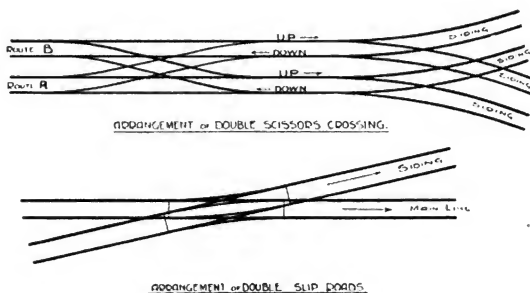


FIG. 3.

Rush hours naturally occur during the morning and evening, but with the greater density in the former, as all the business community and workmen need to travel more or less at the same time to their work. In the evening hours, however, passengers are spread over a longer period, with the result that the traffic is less congested during any one hour than in the morning, due, of course, to the fact that offices, workshops, &c., close at different times. During these hours it is necessary to increase the number and length of trains, and a certain number of composite trains and coaches (which stand idle during the daytime) are therefore kept as reserve, and with the scissors crossings, to which reference has been made, afford means of transferring rolling stock from one side to the other, avoiding a stoppage of traffic. At times difficulty occurs in transferring the locomotive from one end of the train to the other, but in practice this

is overcome by constructing, where possible, a single line circular track leading from the down road to the up, or vice versa, the use of which brings the locomotive into position to proceed in the direction desired. Thus the disadvantage and delay due to attaching and detaching engines are avoided.

In laying out tunnel stations, the platforms (which should be on the island principle) should, if practicable, be placed at the top of an incline, so that the trains would receive an assisted acceleration in speed in starting from, and deceleration in running into a station.

Where lifts or escalators are not provided and levels permit, inclines of reasonable gradient are more desirable than steps, the latter being more tiring to use and more likely to lead to accidents.

In considering the question of the design of surface stations, the engineer has always to bear in mind the provision of spacious platforms, with extensive circulating areas at booking offices or enquiry points, wide staircases, and lifts, or escalators, to give speedy means of dealing with passengers' luggage or parcels, especially at terminal stations. He must always bear in mind the necessity of avoiding as much as possible confusion of traffic, and of providing a ready means of transference from platform to platform, and in addition, as indicated, good vehicular access to the station for motors, goods vans, &c.

With regard to booking offices on platforms, to avoid obstruction of the view to the access to the various platforms, it is desirable to construct them in a semi-circular or torpedo shape. This removes the square corners, which both interfere with the view and also form a considerable obstruction at important points; at the same time it gives a lengthened side for booking and enquiry windows.

The cab or vehicular approach should, over and above providing facilities for discharging passengers, in the case of terminal stations also provide a roadway within the station giving direct access to the platforms for the convenience of long distance passengers. Such roads should be of sufficient width to allow of vehicles turning to leave the station while others are approaching.

The means of access to and exit from a suburban station is a matter of considerable importance. Where possible it should be wide and also have independent entrance and exit, as sometimes during the period of discharging a heavy train, if only one "in" and "out" way is provided, passengers arriving somewhat late may be unable to board the train in consequence of the numbers they meet coming off the platform.

ROLLING STOCK.

Facilities have to be furnished within easy reach of the point where they are required. Engine, motor, and carriage sheds, for storing rolling stock when out of use, for examining, repairing, gas charging, and cleaning, should be provided. The safety of signalling apparatus (including track circuiting, for indicating the position and presence of trains) must always be a prime consideration, and doubtless, in the near future, train control will receive special attention. Where electricity is the power, the question of power houses must be dealt with, and in the case of steam haulage, provision must be made for watering the locomotives, standing or in motion, by means of troughs laid in the track and at the platforms. Coaling, &c., demands attention, while at the engine sheds the necessary auxiliary offices, workshops, stores, sand furnaces, turntables, and coal stages, will be required. In connection with the passenger stock, it is essential to bear in mind that the greatest possible number of people should be conveyed during the rush hours, and with this in view the modern design of suburban stock is that of the non-compartment type. This form of coach seats as many passengers as the compartment pattern, while allowing room for a large number to stand, thus filling the coach to its utmost reasonable capacity. For local journeys it is generally considered to be more comfortable.

Trains should, of course, be run the full length of the platform, or in other words, the train should be as long as practicable.

On arrival at an important or terminal station, passengers should be enabled to be clear of the station and platforms as soon as possible, and in this connection it is found in practice that the collection of tickets at outlet barriers on arrival is quicker than at a station en route. Moreover, this method enables the running roads to be cleared sooner and allows the train following to enter the station whilst passengers by the preceding one are leaving the platforms. The coaches of the first train, immediately after the passengers have been discharged, are refilled by outgoing passengers, and in the case of the same train making a return journey, it is ready to leave as soon as the second train has cleared the crossings at the entrance to the platform.

Barriers have this great advantage, they admit of outgoing and incoming passengers passing from and to the platform simultaneously.

Electricity is, no doubt, the best motive power, and all future lines will, if possible be equipped with it. Considerably better general service can, however, be obtained from existing steam lines, by laying down

additional signal safety appliances, &c., and so speeding up present services. Steam trains cannot gather speed at the same rate as those hauled by an electric motor, and doubtless the latter is more adapted for frequent and quick service, but the author is of opinion that a great deal can still be done to make a steam service more efficient than it is to-day. Indeed, considering the high cost of electrical equipment and plant, it is questionable whether electrification would be justified on many suburban lines at the present time. The whole question of electric versus steam haulage is debatable, but it cannot be questioned that in point of speed, rapid starting and stopping, cleanliness, smokelessness, &c., the former has the advantage, and in addition, engine sheds, with all their accessories, are not required. Its disadvantage lies in the fact that in the case of a failure of current the whole or part of the system is absolutely stopped, whereas in the case of steam haulage, if a locomotive breaks down another can be provided.

The arguments to be advanced in favour of railway traction for dealing with suburban traffic are that large numbers of people can be conveyed in every train at frequent intervals, while in the case of the city or town, where distribution in all directions without interference with the street traffic is desirable or necessary, it can operate at an average speed of 20 miles per hour and convey 500 to 600 passengers.

The author thinks that it must be apparent that at the present rate of suburban development, especially in view of the extension of Housing Schemes, it is hopeless to attempt to supply transport requirements by means of vehicles using the public streets and highways.

The railway system provides for rapid transit from point to point, larger numbers of people are picked up and discharged at a given point, while stoppages are less frequent than in the case of an electric car or motor bus.

The motor bus is a modern development of the horse-drawn vehicle and has attained a certain amount of popularity in cities and towns where the road surface is suitable for such traffic. Wood paving or asphalt appear to be the only surfaces that give any degree of comfort to the traveller by this class of vehicle, indeed it is only where the roads are so paved that the motor bus has come to stay. The speed of these vehicles is regulated by the amount of traffic in the streets traversed, and also to a large extent by the width of those streets, as necessarily a margin of safety must be allowed for vehicles of varying speeds travelling in the same direction, also for vehicles in

opposite directions passing each other without stopping or reducing speed. The routes taken must necessarily vary somewhat as occasion demands, so that in the majority of cases the buses will have been running for some time before the engineer has an opportunity of giving proper attention to the road surface.

One great advantage of the motor bus in a narrow street is its freedom of movement. It can be twisted and turned in and out of the traffic at the discretion of the driver. A disadvantage it possesses is the small number of people it can accommodate protected from the weather, as generally unlike the tram car the outside seats are not roofed in, and consequently in unfavourable weather the outside seats are little used and the carrying capacity of the omnibus reduced accordingly.

Apart from the discomfort of travelling over rough roads, unless a fairly smooth surface is maintained for this class of vehicle to run on, running costs and repairs increase enormously. A single vehicle is able to carry approximately 40 people, and can travel at from 9 to 10 miles per hour.

Originally tram cars were open and horse-drawn, but as time progressed and the demand for transit by this means increased they were covered in and electric traction substituted. The great drawback to the tramway system is its inflexibility, and as a result traffic congestion in the streets is accentuated, and further, should any accident occur to a car itself, or anything foul the tram rails, the movement of all cars on that route is affected.

Travelling by tram car is more comfortable than by motor bus, on account of its smoother running and the fact that the majority of cars to-day are roofed in to protect the passengers from the weather, with windows to open when the elements are favourable.

During the busy time of the day, trailers may be employed to deal with the extra number of passengers presenting themselves, and although the speed of tram car with trailer may be reduced somewhat, still it is an important factor in dealing with the crowds at the rush hours. A tram car travels at from 9 to 10 miles per hour, and is capable of carrying about 80 passengers.

In conclusion, this to be initiated must sometimes have been elementary, but there are probably among those present a few who are not so familiar as others with railway ways, works and requirements, and an attempt has been made to cover the whole ground of the subject, not omitting those aspects of it which may perhaps appear to be obvious.

It would have been desirable to deal with the question of cost, both in connection with the construction of works and operating the traffic, but in view of the cost of materials, rates of wages, and generally the abnormal time through which the country is passing, it is felt that no real value could possibly be assigned to any estimate which could be made at the present time, and therefore it has been deemed more prudent to leave that side of the subject altogether.

The Paper was accompanied by diagrams which have been reproduced as illustrations in the text.

DISCUSSION.

The President

The PRESIDENT remarked that the author in his paper had dealt with a subject which was engaging much attention at the present time, not only from engineers but also from the general public. The transport of passengers in urban and suburban areas was undoubtedly one of the questions of the day that had to be solved, and in no large city was this difficulty more apparent at present than in Liverpool. Here they had a problem that was not the same as in all large cities, as they had to deal with the cross-river traffic, which undoubtedly was an important part of the question locally. The author, as they might have gathered, was obviously a railway engineer, and he appeared to have made out a practical case for the railways. He was also quite justified from his point of view in not omitting to point out any defects that rival systems might have. The author had summed up his case very clearly and frankly on page 199, in the third paragraph, where he said: "The author thinks that it must be apparent that at the present rate of suburban development, especially in view of the extension of Housing Schemes, it is hopeless to attempt to supply transport requirements by means of vehicles using the public streets and high-ways." The author had put the matter before them in a way that would probably stimulate discussion, which he was sure was one of the objects for which the paper was prepared. He expected that in discussing the paper, members would probably consider the problem from the point of view of other systems. He would ask them to accord a very hearty vote of thanks to the author.

Mr. Rettie

Mr. CHARLES RETTIE expressed the opinion that urban passenger transport by train had always been a popular subject. Many years ago he wrote a good deal to the Press with the object of getting the local authorities to go in for electrification. He believed his articles were at the time appreciated, and he had reason to believe contributed in no small measure to the fact that the different lines in and around Liverpool were eventually electrified, at any rate he had lived to see the progress which had been made and statements which he then made, verified. One letter he wrote in 1895 to the "Journal of Commerce" made the statement that the L. & Y. Railway section from Liverpool to Southport was an ideal run for electrification. There had been a good deal of discussion lately on the question of economy.

Mr. H. E. O'Brien, of the L. & Y. Railway, for instance, in a paper given before the local branch of the Institution of Electrical Engineers, had made a statement that it was no use considering the electrification of their railways unless they could show an economy over steam. In the case of all the suburban steam roads throughout the world which had been electrified that he knew of, including the Melbourne Suburban Railways, the latest convert to electricity, with a line of some 300 miles long, and also the * East London Electric Railway, the receipts had more than doubled since they were electrified. If they could give a better service by electrifying the lines and thereby increase the receipts they were bound to take that into account whether electricity was cheaper than steam or not. Some years ago two men in the States drew up a report on the question of a high-speed line to Philadelphia from New York, a distance of 75 miles. It was proposed to run trains at 100 miles per hour, the cost of running was to be double that of the existing steam roads, but the fact that the New York merchant would be able to go to Philadelphia and back in a few hours time would cause more journeys to be made, and no objections would be made by the passenger paying double fare, as he would be able to make two journeys to only one under existing conditions and also he would have more time to transact business. The project was never carried out. There was also a paper given before the New York Electric Club, about 1892, on a proposed line from Chicago to St. Louis, on which the trains were to run 100 miles per hour, but this never materialised.

Mr. Rettie

Coming home to their own city, a high-speed line was proposed from Liverpool to Manchester, Parliamentary powers for which were sought and obtained, but on account of some hitch or want of support, the project fell through. The advantages of a high-speed line to Manchester were obvious, as the merchants could travel either way in about 15 minutes and would not object to paying the higher fare demanded to cover the extra cost of a better service. The question of finance raised by the author was a serious one, and as regarded the long distance lines no doubt would be a detriment to the future electrification of their railways, especially if the conditions were the same in this country as in the States, where the railroad companies

* Editorial of the "Electrician," 11th February, 1921, referring to the recent report of the East London Railway Co., goes on to say: "It appears that during the past year 14,667,000 passengers were carried, compared with 4,224,000 in 1912, the last year of steam working. In the same period the gross receipts increased to £101,300 from £38,000."

Mr. Rettie would be years before they paid off their existing debts * ; so it would be no use talking about electrification until that was done. There was an interesting article in the "Scientific American," for 29th July last, on "Power in Big Packages," an extract of which he would like to quote, as it bore on the enormous possibilities of fuel economy on their railways when they came to electrify on a large scale. Referring to the district round New York covering ground about the size of Great Britain, the writer said: "Inasmuch as the improved "central stations will be able to develop a kilowatt for 17 lb. of coal, "and can distribute within a radius of 150 miles from the source of "generation large blocks of energy at a loss of only 5 per cent., there "is little reason for wonderment in the claim of the technicians that it "will be possible at the start to reduce the annual consumption of "coal in the super-power zone by 30,000,000 tons, if not more."

Mr. J. A. Brodie Mr. J. A. BRODIE expressed his great pleasure at being present to hear the author's paper. As one of the oldest members of the Society he could remember very well when the author's father was an important member of that Society and when he was carrying out railway work locally. He hoped that the author would follow in his father's footsteps and reach the highest position in the profession.

The subject was a very interesting one to many of them. They could have wished, perhaps, that the present relative positions in regard to urban traffic of railways, tramways and motor buses, could have been discussed fully, but he saw the author left the opportunity for a little discussion and for comparison. As a railway engineer, the author naturally (on page 193) put the railways first. He said "Railways, Motor Bus and Tramways." Well, it would be a bold man who would say that the railway was not, under certain circumstances, entitled to the first place. He was not quite so clear about the author's placing of the motor bus and the tram. He thought there was room for difference of opinion as to the position which these two should take relatively, and he thought it was also open to question whether, for short distances up to, say, 8 miles from a centre, the tramways should not take the first place, the railways the second place, and the motor bus the third place. At any rate he was proposing to put them in that position for the purpose of that

* Extract "Scientific American," 22nd January, 1921. Article by Charles Fredrick Parker: "Statistics compiled by the Bureau of Railway "Economics show that in the fourteen years from 1921 to 1934, inclusive, "debts aggregating more than ten billion dollars will fall due and must either "be paid by the railroads or refunded.

discussion. For such distances his own view was that the electric railway had got a very keen competitor in the electric tramways of the future. He noticed that the author left out the question of cost. He should think he had quite a good reason for doing so, but it was one of the matters which must be very seriously taken into consideration, particularly for urban traffic within a distance of 8 or 10 miles of the centre of a large city. The cost of providing additional lines or even of connecting up existing lines in many cases would, he thought, probably prevent extensions which would be of advantage to the travelling public. They all knew what the cost of tunnelling was at the present time and what it was likely to be in the future, and to give a reasonable service for distribution in the centre of a city such as Liverpool, on electric train lines, very heavy expenditure would have to be incurred. As against this, the tramway at the present time was economical in construction and could be economically worked. The question of capacity was also one which would have to be taken into consideration. He could not give the exact figures, but roughly he should say that the heaviest tramway traffic lines were now carrying two to three times the number of passengers, during the rush hours, than the best electric train service out of Liverpool was carrying. The author had raised the question of the carrying capacity during the rush hours, and it was a very important point which appeared to favour tramways. It was probable that the tramways of to-day would have to be modified and speeded up to meet future requirements, and he saw no reason why tramways should not compete in the matter of speed, over short distances, with the electric train system up to 6, 8 or 10 miles from the centre of the city, which was the question of greatest interest in a city such as Liverpool.

They were at the present time putting down housing accommodation from, say, 5 to 6 miles from the centre of the city and the question of cheap, quick and convenient means of transport was very important and would have to be faced. It had been said that the solution would be by way of the electric train. He thought part of the solution might be in that direction but his own view was that in any case it would only be a small part. He saw some figures published as to the relative carrying capacities of the whole of the railways as compared with the street method of conveyance in London, and it was rather interesting to him to see that the rate of increase during ten years before the war of the street service carrying systems was five times as great as the rate of increase of the corresponding railways; that, he thought, also tended to prove that the

Mr. J. A. Brodie

Mr. J. A. Brodie electric train service would, under urban conditions, have great difficulty in holding its own. The author said: "It is hopeless to attempt to supply transport requirements by means of vehicles using "the public streets and highways." He would not fall out with the author on that, but what he did say was that it was five times more hopeless to provide accommodation by means of electric railways. The electric railway, according to his view, provided reasonable accommodation for passengers within a distance of, say, half a mile from the station, whereas the tramway on the other hand provided proper and reasonable accommodation for residents within a quarter of a mile of the tramway track on either side. If that basis was correct then it would appear they would have to provide for half as many miles of electric railway to meet the requirements as they would of tramways, and if they took the relative costs of construction into consideration, they would see that the electric train system for purely local traffic had probably a very uphill fight under existing conditions. The motor bus was quite useful for certain purposes, but under existing conditions it could not compete with the tramways, and it was just as well to have this figure before the members of the Society. The cost of running a motor bus per seat mile was in some published figures given as 214 per cent. of the cost of the running of a tramway per seat mile including all costs, or rather more than twice as much per seat mile as the tramway, and so long as a relative cost of that kind existed the motor bus would have a difficulty in holding its own. What were proper conditions for tramways in a great city in the future? They had got to the end of the life of the existing tramways; they were started in 1898, and large expenditures would be required both in reconstruction and extension, and the probability was that at any rate for the outer districts it would be necessary to provide roads on which high speeds could be safely run. High speeds could not be safely run in any city on narrow roads, and therefore he got back to an old subject of his, and after 20 years' experience of wide roads he was still convinced that looking to the future of traffic on roads in large towns far wider roads than ever would be required.

Mr. Mills Mr. W. E. MILLS desired to associate himself with what had fallen from Mr. Brodie with regard to the author's father. He had the honour of being a member of that Society when Mr. Ross occupied the Presidential chair, and he had a very warm and affectionate remembrance of all the interest he took in the Society and his conduct of the discussions which took place in those days. The author had summed up, on page 193, certain conclusions that he had

come to as the leading factors for the success of urban passenger traffic. With reference to No. 1—"The provision of means for the "transit of the largest possible number of people in a single movement," he was not quite sure whether the author meant by that that a passenger should be conveyed from the time he entered the vehicle to his destination without transshipment in any way, but presumed that was what was meant. Then again, as to No. 4—"The provision of connecting lines running from the heart of a city "or town to the rural districts adjacent," that, he thought, opened up a very wide question as to what the main feature of the design of the early railway engineers of this country was in laying out the main trunk lines. He remembered his father saying, when he was on the Committees of the House of Commons on various railway schemes, that the leading engineers of that day were possessed with the idea that the proper way to lay out a railway system, in any given country, was to lay out the main trunk line, proceeding, say, from the Metropolis to some other leading city, after the manner of the stem of a tree, with certain branches at intervals to towns which were of importance and had to be served, but which lay off the direction of the main trunk lines. He thought that if anyone studied the railway map of Bradshaw's Guide at the present time, he would see that this principle, although it was adopted in the case of the Great Northern and to some extent in the case of the Great Western Railway, had been very largely departed from in practice since, and if there was no explanation of the point, the multiplication of lines, especially in the manufacturing districts of this country, would seem to be utterly meaningless, the lines overlapping and running in curves and twists for no earthly reason apparently. There was a reason, of course, but it had always seemed to him that the early engineers were wrong in their idea, but the reason was that they never foresaw the enormous development of the railway traffic of this country. If a central controlling authority had had the laying out of the whole of the lines of this country, they would have best served it by instituting a system of triangulation. They saw a line starting out from the main line and going out to the left or right hand of the line until it fell into the same line higher up or lower down, as the case might be, whereas if the short sides of the triangle had been introduced, a great deal of expense and time would have been saved and the travelling public would have been better served, but of course it was too late to talk of that now. That led him up to what the author said on page 193: "In designing the track of main or trunk lines, the original scheme

Mr. Mills

Mr. Mills "of the first railways, apparently, was to run them straight into the city "or town and terminate with a station (Fig. 1) indicated by the thick "black line ending with a block marked 'station' but, as the "population increased, it became necessary to extend outwards by "constructing branch or belt lines," and the author went on to say : "This form of railway layout was no doubt adopted to avoid the "congested areas and also to make provision for a larger district by "having a number of stations," &c. He was inclined to join issue with the author on that point because, in those days of early railways, there were no congested areas.

He thought that the engineers of that day simply took a map and said they wanted to get from, say, London to Edinburgh, and they would go as straight as they could subject to the contour of the country and the necessary deviations to save extra tunnelling and other expensive work. If they looked on the map at the Great Northern line they would see that it was a fairly straight one between the two points. In Fig. 2, the author showed by the various black dots what were connecting branch lines in London, but these were all underground, and he thought that the author had rather missed the point there, because what they wanted to know was, how could the existing railways supply suburban traffic to the extent which large towns at the present day demanded. If the only solution was a system of underground railways and tubes, such as they found in London, that was one thing. If, on the other hand, the existing railways doubled their width and ran the suburban traffic on the one set of tracks with the main line traffic accommodated on the other set of tracks, that was another thing, and it would be interesting to know how far the author suggested the one system or the other should be employed. The great object of the underground system of railways was to avoid interfering with the street traffic, but he thought that in towns, if the railway traffic was carried to a central station by a viaduct which carried the line over the streets, it would not interfere with the street traffic.

There was one question he wanted to ask, where the author suggested at the bottom of page 197 : "Inclines of reasonable gradient "are more desirable than steps." He quite agreed with the author, but he would like to know what rate of incline he had found in his practice was the greatest that could with safety be adopted, and the point at which it became better to introduce a staircase rather than a sloping roadway. They passed then to the question on page 199, where the author said : "It is hopeless to attempt to supply transport require-

“ments by means of vehicles using the public streets and highways.” Mr. Mills
 They had all been familiar with the arguments advanced of the advantages of the motor bus over railway traffic, and he thought as far as his observation went that in a short journey such as a motor bus was able to undertake—he did not say its capacity—it of necessity had an advantage over the railway. The railway was fixed in the same way as the tramway lines were fixed, but a motor bus could stop anywhere, and if the ordinary route were blocked it could take another route, but if a railway was blocked the traffic could not be carried on until the obstruction was removed, and there were subsidiary advantages which would commend themselves to everybody. In point of speed the railway must have the advantage, but that was only valuable where the passenger went from the central station to a point, say, 10 miles distant or upwards, and he failed to see that with what might be termed “pick up” traffic the railway could possibly compete against the motor bus. He would be told, of course, that he had forgotten the much greater number of passengers the railway train could carry than the motor bus. That must be admitted, but he thought that if they could show that they could run motor buses at shorter intervals than the trains, the advantage would remain with the motor bus.

In weighing the merits and demerits of the railway versus the motor bus, was not the length of the journey an important factor? He could quite see that on a long journey the railway would win hands down, but on a short journey he was of opinion that the motor bus would have the best of it, but he was not prepared to say at what point the division would take place, and he would like the author to give them some information as to that particular dividing line. It was stated at the top of page 200: “A disadvantage it possesses is the “small number of people it can accommodate protected from the “weather,” but he would submit that was only a question of design. If it was found that the motor bus was a very important factor in suburban traffic it could surely be designed to protect its passengers from the weather. The argument on the same page: “The great drawback to the tramway system is its inflexibility” held good for the railway, which was as inflexible as the tramway, and the only advantage the railway had was its superiority in speed, but as Mr. Brodie had said, in the near future they might expect to see motor buses hurtling along their streets, equalling if not exceeding the speed of the best equipped electric railway. The author had very prudently omitted any question of cost, but to any authority that had to face the problem the cost would be a very important consideration. He thought one

Mr. Mills particular point on which they would like information, was in the case where railways already existed, as to what the author would suggest as the best means of adapting them to the suburban traffic, which must require accommodation in any railway that had a central terminus in any given town. There would be a very large suburban traffic to be catered for and he thought that it was a very interesting problem to see to what extent the existing railways could be altered or adapted to suit that traffic. They knew that competition was prolific in providing schemes to meet difficulties and the railways had to meet the competition of the road vehicles. Most of the large towns had central stations forming the terminals of their main line, but these the engineer probably looked on as merely a terminus for his London traffic. He had nevertheless all the suburban traffic to contend with as well, and it would be very interesting to hear what the engineers who were studying this problem had to offer them, with a view to adapting the present system of railways to that problem.

**Eng.-Capt.
Ward**

Engineer-Captain J. T. H. WARD said that he assumed that the matter of urban transport depended very largely on the return for the capital outlay as well as convenience in the transport of passengers, and it appeared to him there was a great field for both the railway train and the tram car. There was bound to be overlapping where points would be served by both services, and he feared that railway trains could never be run so frequently or in so many directions as the tram cars. On looking at Diagram 2, if that represented the railway system of a very large city, much larger than Liverpool, it was possible the distance between extreme points might be as much as 25 to 30 miles, or even more, in which case the railway stations would be so far apart as to leave large areas unsupplied by the railways, and how could these areas be more satisfactorily supplied than by tram cars? The tram routes could easily be laid out to run almost anywhere, whereas from financial and geographical reasons railways could not be run on so many routes. In a large city, such as in Diagram 2, it appeared almost as if a passenger might take train to his nearest railway station and yet be so far from his destination as to need to complete it by tram car. Tram cars practically passed one's door and if one had to walk from 5 to 10 minutes to a railway station, and the same at the other end to one's destination, although the railway train travelled much faster, it was highly probable that it would take longer to cover the whole distance travelling by train, than to jump into a tram car at one's door and get out at one's office (a most important condition in bad weather), and he considered that the majority of

passengers would travel by that route which carried them the quicker from door to door. Eng.-Capt.
Ward

Mr. F. E. G. BADGER thought that it was very opportune that the author had been persuaded to give a Paper to that Society on the transport of passengers at the present time, because many of the members were interested in that particular subject. There was no doubt that the congestion on the streets in most of the large towns at the present day was very serious and would become increasingly serious in the future, and that was sufficient excuse for their discussions at various times on transport matters. Mr. Badger

The author had referred once or twice in his paper to housing schemes, and Mr. Badger happened at the moment, on behalf of Liverpool, to be interested in the housing schemes in the suburbs. Undoubtedly the two questions of housing and transport were closely allied, each, so to speak, being dependent upon the other. Shortly, the Corporation were developing an estate at Fazakerley, adjoining the station, which was served by railway and also by tramway. Several thousand houses were being erected on the Larkhill estate which would have convenient tram services, and along the borders of the estate there was the Cheshire Lines Railway. Then a little further along this railway they had the bungalows at Knotty Ash, also conveniently situated alongside the tram route. Elms House, Old Swan, and Edge Lane Drive estates were suitably provided with tram services. The Mossley Hill estate was situated alongside the L. & N. W. Railway station, and a main arterial road 120 feet wide, with tram lines in the centre, passed through the middle of the estate on to another site at Allerton, where some 2,000 houses were now in course of erection. This last named estate would also have the convenience of the L. & N. W. and Cheshire Lines stations at Allerton and Garston, which were quite close to the area. From this it would be seen that the Housing Committee had carefully considered the question of the transport of their future tenants.

They had, as in most other engineering matters, differences of opinion as to the best method of transport; one school pinned its faith to the street tramways, whilst another was just as strongly in favour of a further development of the railways, but he supposed that, as usual, a compromise of the two systems would bring about the best result. Some form of road transport was undoubtedly essential for a vast number of the population of Liverpool which would present a problem for all time, but those citizens who had migrated to the suburbs and had experienced the greater comfort of a quick railway service,

Mr. Badger claimed that this form of transport was, in their opinion, the only one possible.

However, speaking particularly of Liverpool, and in respect of Diagram 1, it seemed to call for co-operation between the two methods of service. The full black line on the left was the L. & Y. Railway, the middle the L. & N. W. Railway, and the one on the extreme right the Cheshire Lines Railway. The last named railway branched to the left, shown by the dotted line, at Hunt's Cross, and followed a Northerly direction as far as Aintree, when it curved round to the left again towards the city, terminating at the small black square on the diagram, which represented the old Huskisson Station. This dotted line travelled through some of the most beautiful country one could wish to see, and was ready for intensive house development. Now between the dotted line referred to and the present outskirts of the city there was a large belt of very fine country which should, for the most part, be reserved in perpetuity for the benefit of the citizens as open spaces and playing fields.

He recommended the intensive development of house building abutting the Cheshire Lines Railway on one condition only, viz., the coupling up of the three terminal stations in the city, by running a tube from Huskisson Station to Exchange Station, then along to Lime Street Station, and finally to the Central Station, by which means a complete circuit would be obtained and passengers would be able to travel from any portion of that railway across the river to the Cheshire side by means of the Mersey Railway at Central Station, without passing over the public streets.

The length of the circuit was, roughly, 18 miles, and the half-way point was situated between Gateacre and Childwall Abbey Stations, which point was, therefore, situated 9 miles from the centre of the city. By the electrification of the Cheshire Lines Railway the journey in either direction from the furthestmost station on the circle could be accomplished in from 23 to 26 minutes, and by the acceleration of certain trains this time might be reduced to even 18 or 20 minutes. It would be well worth while utilising to the utmost a railway which was designed by a man who must have known there would be a Finance Act in 1910 and a shortage of houses in 1921.

He had read the paper carefully, and he was very much in harmony and sympathy with the author's views, but at the same time it should be remembered that a very large section of the public must be conveyed to and from business on the roads, and at the moment the commendable and important developments now being carried out

by the City Engineer, Mr. J. A. Brodie, were being jealously watched by interested persons all over the world. Mr. Badger

Mr. S. A. KELLY agreed with Mr. Badger that there was indeed room for the railway, as well as the tramway and motor buses, in supplying the wants of urban transport in their city. Mr. Kelly Mr. Brodie had stated that the effective area of the railway ran to a distance of about half a mile each side of the line and of the tramways one quarter of a mile each side of the line. Now, when they realised, from that excellent diagram the author had prepared, that in Liverpool there was a distance of from 2 to 3 miles between the black lines and the dot and dash lines, they must realise that it was impossible to have new railways in those areas, and they must have an effective transport system there. No doubt the electrification of railway lines would prove, as it had done in the case of the L. & Y. Railway, a great success, but even there they had electrical tram lines running practically parallel with that railway through parts of their city, and both carrying a tremendous number of passengers during the business hours of the day. No doubt development of the motor bus would be more effective when specially selected roads were provided for them, having a resilient surface of wood block or asphalt. In new roads the adoption of something better as a finishing surface than the ordinary water-bound macadam road was imperative, and that, no doubt, would be taken into consideration in those large areas which were now being developed, so that motor buses might be profitably run.

The suggested high-speed tramway was, no doubt, the best development they could have for the wide radial roads in the suburban areas, and motor buses as auxiliaries for linking up the circumferential roads. The difficulty in the high-speed tramway was when it approached the town and they had to come down to a more moderate rate of speed, owing to the congested state of the streets, but it might be possible to arrange some central areas for the circulation of the tramway traffic and not to impinge practically the whole of the system on one point, like it did at the present time at the pierhead. High-speed cars might have to come down to half-speed when only half a mile from the city, or it might be possible to change into a different form of vehicle of a lower rate of speed to come into the town. The reason, no doubt, for the popularity of the L. & Y. Railway, was the fact that the Exchange Station lay more in the heart of the city than the other terminal stations, and that was a great factor, especially for the city worker, because he liked to get as near to his work as possible,

Mr. Kelly and also because he was enabled to buy a contract and travel at a cheaper rate. Possibly they would find their Tramways Committee using the wisdom of foreign countries and giving contract tickets which would have the photograph of the passenger attached to prevent misuse. There was no doubt about it, a contract service would be a great asset at the present time to the tramway. He had listened with great interest to the author's paper, and he felt that at the present time, when reconstruction was so much before them, the author had given them a most interesting paper and presented several ideas which might be well thought out and used to the benefit of the City of Liverpool.

Mr. T. MOLYNEUX remarked that reference had been made by the author to the L. & Y. Railway, from Exchange Station to Southport, and, taking the rush in the evening from 5-30 to 6-30, there was a train running out to Hall Road every 5 minutes. The trains were packed and he imagined that the Railway Company was about at its wits end what to do with that particular section. He doubted whether any more trains could be placed on that length with safety. He also imagined that they were regretting that they had not got the old broad 7-foot gauge. That would give them, undoubtedly, an extra 20 or 25 per cent. more accommodation in their carriages without lengthening the train, which was, perhaps, a very serious matter in closely worked sections of that description. It was an ideal length of line for attempting to get back to the old 7-foot gauge. The main line traffic of the L. & Y. Railway practically left the line just after Sandhills and the line was clear for purely suburban traffic, and the engineering works, in his opinion, would not be a very difficult matter, certainly not after Waterloo. The author in his paper, on page 198, had expressed the opinion that electricity would be the factor in the future as regards power, but in the paragraph he said: "Considering the high cost of electrical equipment and plant it is "questionable whether electrification would be justified on many "suburban lines at the present time," and then on page 199, the paragraph which had been mentioned on more than one occasion, the author stated: "That it must be apparent that at the present rate of "suburban development, especially in view of the extension of "housing schemes, it is hopeless to attempt to supply transport "requirements by means of vehicles using the public streets and "highways." Frankly, reading that paragraph, he was very puzzled after the author's previous statement, and he came to the conclusion at the finish that the paragraph was made in all sincerity, and he

ventured to think and suggest to the author that it would not lose any of its sincerity had the paragraph ended "by railway system." With regard to page 195, the author rather tried to make a distinction of the duties of the traffic manager and the engineer. Mr. Molyneux could not quite see how they differed, seeing that the traffic manager was really an engineer in the strict sense of the term, and he could not see any distinction between the two officials in modern railway working.

The AUTHOR, in reply, said that he was very much obliged to the members for the way in which they had criticised the paper, especially those who had adversely criticised it. One of the first speakers had referred to the question of the receipts having doubled. Capital costs at the present time were about three times what they were in 1913. He presumed that if set against the 1913 receipts any capital expenditure was out of the question at the present time. At the same time there was no doubt that work would have to be done to meet the ever increasing demands of the traders and housing demands. Speed in suburban traffic was a great saving in time, therefore, assuming that they put down electric traction, it would give a considerable amount of saving of time to the travelling public. He was very much obliged to Mr. Brodie for the very kind remarks he had made about his father and he appreciated the good wishes for the future. Mr. Brodie thought the tramway should come first, and as a tramway man no doubt Mr. Brodie did, but as a railway engineer he personally thought that there was room for them all, if some arrangements could be made by which the railways could take the long distance passengers and the tramways the short distance passengers.

He had noticed particularly that on the suburban lines a great many people joined the trains at terminal stations and got out at the next station, which might be only a mile or a mile and a half distant, during the rush hours. In many cases this distance was provided for by tramway services, and it seemed to him that these short distance passengers should be prevented from joining the trains, and the tramway should cater for them. If some arrangements could be made between the tramways and the railways he thought that they would benefit. With regard to the motor bus, he thought that the time had hardly come for the motor bus. In London, of course, it was different, because there the streets were paved with wood, but in the majority of large cities they had many streets paved with sets and it was not a very good surface and the passenger was not over comfortable in the bus. The carrying capacity of a train during the rush hours, of

The Author course, was greatly increased because so many people stood. He thought that was one thing they wanted to attain to—the larger number of people in a single movement of a train. They got about 600 people, and in the case of some of the race trains going out to Aintree they got up to 1,000. They cleared the train and in three minutes they got another train with another 1,000, and it meant moving a large number of people in an hour.

What he intended to convey in paragraph 2 on page 199 was, that if they were going to put more buses and trams on these streets by bringing them in from the country, they had to widen their streets. The streets of the majority of the towns to-day were taking all they could. What some Corporations proposed to do was to run their trams as additional to that. That was all right for a certain distance, but when they brought them into the town their streets were already congested and they were bringing more congestion on to the streets, and the question arose as to widening the streets, but were they going to widen the streets or have tunnels underground. One speaker had referred to Fig. 2, on page 194; that was more or less a diagram of the suburban railways of London, and that was not quite correct because it was not up to date. They went right to the heart of the city by the tubes and ran right out, and that was what he intended in the paper. He was referring to Diagram No. 2 referred to by Mr. Badger. No doubt it would be a very important factor in dealing with suburban traffic. One speaker had said that the remark made in the paper that the trams were inflexible also applied to the railways. He agreed, but he thought that the circumstances were different. For instance, the tram was on a congested route. With the railway, although it was inflexible, it did get a clear route to run on. The only thing he could suggest, in order to adapt the present railways to meet the problem, was that they should go in for more up-to-date signalling and modern appliances. Of course there was the question of the speed; if they were to develop it would mean going down a fraction.

2nd March, 1921.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,

President, in the Chair.

The Council reported that the following elections had been made:—
WILFRID SWANWICK BOULT, as *Honorary Life Member*, and NORMAN
NATHAN MAAS, as *Member*.

“Cowlyd Waterworks.”

BY CHAS. F. FARRINGTON, A.M.I. Mech. E.

CONSTITUTION OF THE CONWAY AND COLWYN BAY

JOINT WATER SUPPLY BOARD,

AND A DESCRIPTION OF THEIR EXISTING WORKS.

THE Conway and Colwyn Bay Joint Water Supply District was formed by virtue of the Provisional Order of the Local Government Board, dated the 10th day of June, 1891, and confirmed by the Local Government Board's Provisional Orders Confirmation (No. 14) Act, 1891; whereby the Urban District of Conway, known as the Borough of Conway, the Urban District of Colwyn Bay and Colwyn, and parts of the Rural District of Conway and Glan Conway were formed into a United District called the Conway and Colwyn Bay Joint Water Supply District, of which the governing body is the Conway and Colwyn Bay Joint Water Supply Board, for the purpose of procuring a common supply of water for the constituent districts, and for the purpose of acquiring lands and carrying out all works connected with and incidental to procuring the same, and of conveying water for distribution by the Urban and Rural Councils for the said districts.

Orders referring to, confirming and modifying the above Provisional Orders, are known as the Local Government Board's Provisional Orders Confirmation (No. 8) Act 1896, and (No. 9) Act 1898.

Llyn Cowlyd is a natural lake situated in the heart of the Carnarvonshire range of mountains, about four miles from Llanrwst, three miles from Trefriw, and two miles from Capel Curig.

Its extreme length is nearly $1\frac{3}{4}$ miles, and its extreme width over a quarter of a mile. The surface of the lake is 1,169 feet above Ordnance datum, and has an area of about 200 acres. The watershed, which is now owned by the Board, is of a mountainous character, free from human habitation or cultivated land, and rises precipitously on one side to a height of 2,621 feet above Ordnance datum (Pen Llithrig-y-Wrach), and on the other side to a height of 2,213 feet above Ordnance datum (Creigiau Gleision), and is closed in at the Capel Curig end by a slight elevation of about 1,450 feet above Ordnance datum. Inclusive of the lake this watershed has an area of about 1,100 acres, with an average annual rainfall of 90 inches. Llyn Cowlyd is of enormous depth, soundings having been taken about the middle of it down to over 40 fathoms without touching the bottom.

The analysis of the water proves it to be most excellent for domestic use.

At the inception of the scheme the joint owners of the lake made various stipulations, one of which was that the Joint Board should deliver a supply of compensation water into the stream amounting to 1,552,500 gallons every day of 12 hours with a provision of a sufficient supply for cattle on the seventh day. To secure this amount of water, together with that required for the supply of the district, it was necessary to construct an embankment across the end of the lake, 176 yards in length, to impound 13 feet of water or about 700,000,000 gallons. This embankment is formed of earth work with an inner core of concrete and clay puddle, the inner slope of the embankment being 3 to 1, pitched with stone grouted with cement, and the outer slope 2 to 1, revetted with grass.

The water is drawn from the lake through a cast-iron standpost, 18 feet high and 3 feet internal diameter, with two 24-inch valves, at 6 feet 6 inches and 13 feet below top water level, regulated by gearing from the top of the standpost.

Water is drawn from the lake through S. and F. cast-iron pipes, 24-inch internal diameter. These are laid from the standpost, a distance of 492 yards to the gauge chamber 1,154 feet above Ordnance datum, which contains the necessary machinery for controlling the supply of water to the district and for regulating the compensation water, which is delivered at this point into the stream. The inflow and outflow of all the water for compensation and for the supply of the district are controlled by means of valves and penstocks with indexes.

From the gauge chamber the water is conveyed in stoneware pipes,

a distance of 4,100 yards down the valley to the overflow tank 750 feet above Ordnance datum. The pipes are 15-inch and 12-inch internal diameter, according to inclination, with inspection chambers at every change of inclination or direction.

From the overflow chamber, for a distance of 550 yards, the water is conveyed in cast-iron pipes, 12 inches internal diameter, to two pressure reducing tanks, 500 feet above Ordnance datum, from which the supply to the district is drawn. The supply to the district is regulated by means of special valves, and any surplus water coming down from the lake is forced back and discharged into the stream at the overflow tank, 750 feet above Ordnance datum, this being one of the conditions arranged with the riparian owners at the inception of the scheme, so that the water discharged at this point could be utilised for other purposes.

From the pressure reducing tanks the water flows in a duplicate line of S. and F. cast-iron mains, each 12 inches internal diameter, for a distance of 500 yards to the main road at Dolgarrog, at an average gradient of 1 in 3. From this point a line of 12-inch internal diameter cast-iron pipes is continued along the main road, on the Carnarvonshire side of the river Conway, through Conway, Llandudno Junction, Sarn Mynach, and Colwyn Bay, to Pwllcrochan Avenue, and from there is continued in 9-inch internal diameter cast-iron pipes through Colwyn Bay and Colwyn to Llysfaen, a total distance of over 18 miles from the lake. A further line of 15-inch internal diameter cast-iron pipes is laid from Dolgarrog across the river Conway to the main road on the Denbighshire side and is continued along the said main road and lands through Tal-y-Cafn, and Glan Conway to Sarn-y-Mynach, a distance of about 8 miles, where at this point it is connected with the 12-inch internal diameter cast-iron main previously referred to.

The various Authorities entitled to the supply have connections to the trunk mains and Deacon Waste Detecting Meters are fixed upon all branches.

On the 12-inch pipe line two girder bridges, one 45-feet span and another 38-feet span, were erected for the purposes of carrying the pipes over streams, and at Conway a duplicate line of 9-inch pipes is carried over the river by means of a steel wire rope suspension bridge, at a height of 20 feet above highest spring tide, 326-feet span, erected between the Stephenson's Tubular and Telford's Suspension Bridges. On the 15-inch pipe line the special works include a duplicate line of 15-inch mains laid under the river Conway and also a steel girder

bridge, 140-feet span, across the river, carrying two lines of 15-inch mains.

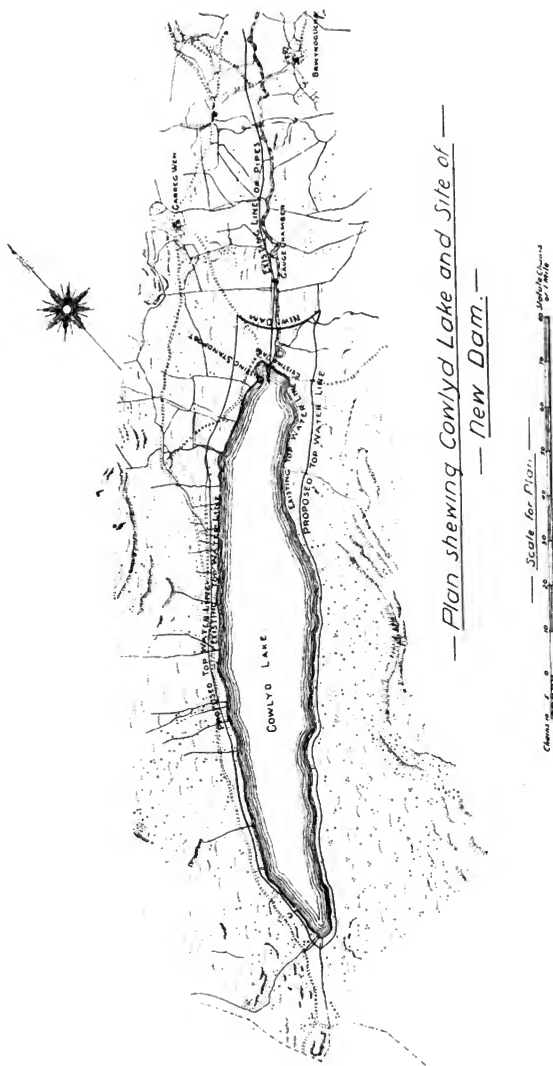
The author had the pleasure of being closely associated with the carrying out of the work in connection with the laying of the 15-inch internal diameter cast-iron main from Dolgarrog to Sam-y-Mynach, the duplicate pressure reducing tank, and the crossing under the river Conway, completed in 1908, and was responsible for the work in connection with the steel girder bridge across the river Conway, carrying the duplicate lines of 15-inch mains, completed in 1916. All other work was designed and carried out by the author's father.

The Board, having become the owners of the Watershed draining into Cowlyd Lake, and being restricted under agreements with various owners as to the supply to the district, obtained powers in Parliament in 1908, confirming the construction by the Board of their existing works, and conferring upon them further powers. One of the main points they were desirous of obtaining was a reduction in the amount of compensation water to be delivered into the stream daily, viz., 1,552,500 gallons per day, the total run off from the watershed being 4,092,000 gallons per day. The Aluminium Corporation Ltd., who had acquired considerable riparian rights in the Cowlyd Valley, were successful in procuring a protective clause leaving the compensation water at the same amount, viz., 1,552,500 gallons per day, and a further clause to the effect that the Board should not alter, enlarge, or extend the embankment or the gauge chamber and the works contained therein, except with the consent, under seal, of The Aluminium Corporation Ltd., such consent not to be unreasonably withheld.

THE ALUMINIUM CORPORATION LIMITED, WORKS, &C.

The Aluminium Corporation Ltd. have extensive works at Dolgarrog in the Conway Valley, where electricity is generated on a large scale by water power for heating the special furnaces used in the production of Aluminium. These works include a Power House (in which the turbines and dynamos are fixed), a furnace room, rolling mills, carbon factory, &c.

The main supply of water is obtained at present from Llyn Eigiau, situate in the adjoining watershed to Cowlyd and north of it, where a concrete dam has been constructed. This lake is further augmented by the surplus waters from the Dulyn and Melynllyn Watersheds, which lakes are the sources of supply for Llandudno, and which are in the adjoining watershed to Llyn Eigiau. The latter water is conveyed into Llyn Eigiau by means of a tunnel driven through the



— Plan shewing Cowlyd Lake and Site of —
 — New Dam. —

FIG. 1.

mountain between the two valleys. From Llyn Eigiau the water runs down the natural stream for about two miles and is then conveyed by means of a catchwater to a concentration reservoir situate on the 1,000-foot contour, immediately above the Aluminium works. Leading also to this concentration reservoir is the Cowlyd Valley catchwater, which delivers the compensation water sent down from the lake.

The Aluminium Corporation also derive the benefit of waters falling on the Eigiau and Cowlyd watersheds, between the lakes and the concentration reservoir.

From the concentration reservoir the water is conveyed to the Aluminium Works in 36-inch internal diameter steel tubes, and as the works are practically situate at Ordnance datum, a head of 1,000 feet is available.

INCEPTION OF THE NEW DAM.

The long drought in the Summer of 1915 caused great anxiety to various authorities and their engineers in this country, and such anxiety was experienced by the Conway and Colwyn Bay Joint Water Supply Board, when as late as 22nd October it was found necessary to issue special notices appealing to all consumers of water within the Board's area of supply to exercise the greatest caution in the use of the water, and drawing attention to the fact that unless the daily consumption was considerably reduced, the Board would have no option but to restrict the supply, owing to the lake being exceptionally low, and at the same time requesting the consumers to desist from using the water for swilling flags, watering gardens, or other wasteful purposes, and to exercise the greatest economy in using it for domestic purposes. The notices had a beneficial but insufficient effect, and the drought continuing, it was found necessary to restrict the supply to the district on the 8th November, when there was only 20 days' storage in the lake to cover the supply to the district and compensation water.

The Board, realizing the fact that the time had arrived for the immediate consideration of the future supply to the district, instructed the author to report upon a scheme for improving the same, and in January, 1916, the author reported that the first portion of any scheme should deal with the waste water at the overflow tank, as, owing to the water being conveyed in earthenware pipes from the gauge chamber to that point, it was necessary, in order to maintain a full supply and keep the trunk mains full of water and to provide for emergencies

during the period of maximum demand, to send down from the lake an additional quantity of water to that required for the average demand. This meant that 750,000 gallons per day were running to waste at the overflow tank, and from careful gaugings taken, it was found that during the period of maximum demand it would not be safe to reduce this. The author recommended the laying of cast-iron pipes with a further pressure reducing tank as soon as was possible, in lieu of the existing earthenware pipes from the gauge chamber to the overflow tank, which would mean the retaining of the 750,000 gallons per day in the lake for the use of the district, with a further recommendation that the Board should give immediate consideration to the advisability of procuring powers for the acquisition of further areas of gathering ground at each end of the lake, amounting in the aggregate to about 1,140 acres, on which catchwaters could be constructed to convey the water into the lake where the storage would be increased by the construction of a new dam immediately below the existing one for impounding the additional water.

At this time negotiations were also taking place between the Board and the Aluminium Corporation Ltd. with regard to a joint scheme, the latter Corporation, as before stated, having acquired considerable riparian rights in the Cowlyd Valley at the Northerly end of the lake, and having also purchased Ffynnon Llugwy and other rights in the Llugwy Watershed at the Southerly end of the lake. These negotiations culminated in an agreement being entered into on the 27th May, 1916, between the two parties.

Under the Agreement, the Aluminium Corporation are to construct at their own cost the New Dam in accordance with plans, working drawings, and specifications approved of by the Board, such Dam, when constructed, and its incidental works to be the property of the Board, but maintained by and at the expense of the Corporation. The Corporation is to have control of its own outlet, and liberty to inspect the Board's works, with full power of ingress, egress, and regress for the purpose of inspection, repairs, maintenance, supervision, and otherwise over the lake, and the works of the Board in connection therewith.

The Corporation is to release the Board from its obligation to supply the Corporation with any compensation water and indemnify the Board against the claims of any riparian owners along the Cowlyd stream to compensation water, by the provision of sufficiently increased storage capacity beyond the present capacity of the existing lake, wherewith to satisfy any such claims.

The Board and the Corporation (after the completion of the New Dam, and the bringing of the same into use) will be entitled to draw the available water in the lake above the level of 1,169 feet above Ordnance datum, or such other height as shall be agreed and determined for the purposes of their respective undertakings, but the Board will alone be entitled to the whole of the water in the lake below 1,169 feet above Ordnance datum, or such other height above Ordnance datum as shall be agreed upon. The Corporation, for the purpose of taking water from the lake in accordance with the agreement, is to construct and maintain an outlet at a point on the New Dam, in such a position, that the lower part of the invert of the pipe shall not be at a lower level than 1,169 feet above Ordnance datum, or such other height as aforesaid.

The Corporation is to be at liberty to bring waters into the new lake from any other watersheds, provided the Board is satisfied that such watersheds are free of all human habitations, and that the water is pure and of a character suitable for the Board's duties and powers, statutory or otherwise, and in the event of it being found, subsequently, that any watershed from which water is so brought into the lake is contaminated or the water therefrom polluted, the Corporation shall, upon receiving due notice from the Board, cut off and cease the supply of such water into the lake. The Corporation, under this condition, is now preparing a scheme for bringing in the waters from the Llugwy and Idwal watersheds into the new lake by means of catchwaters and a tunnel.

The Corporation also undertakes, at its own expense, to clear the land lying between the existing dam and the new dam, and also such portion of the land adjoining the lake as shall become actually submerged by reason of the erection of the new dam, of peat, heather and any other vegetable growth or deposit which would impair the quality of the water.

The Board, at its own expense, has full power and liberty to enlarge its existing lines of pipes, or to lay other lines of pipes for the purpose of conveying water from the lake to the constituent districts of the Board, as existing at the date of the agreement.

The Board agreed, after the passing of the necessary Act of Parliament, to give a continuous supply of water from the lake to the Parish of Dolgarrog, and the house known as "Plas Maenan," for the use of occupiers of shops, private houses, cottages, and other premises there, on the same terms and conditions as those on which the Board supply water to the constituent districts.

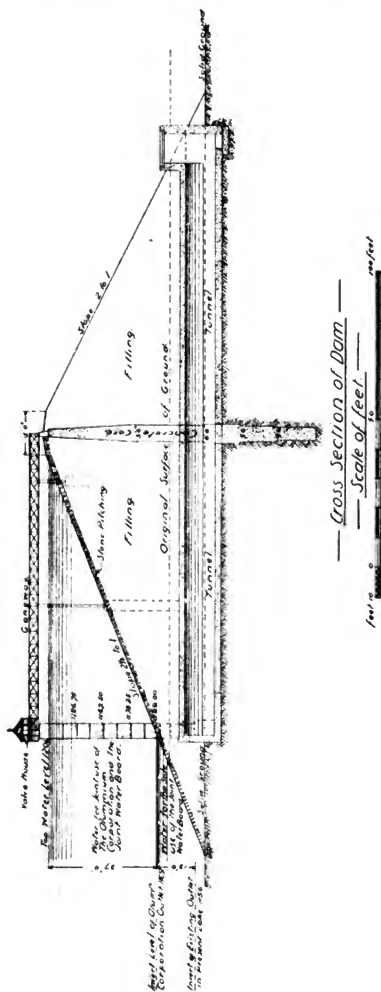


FIG. 2.

The necessary plans, sections, and book of reference, were duly prepared by the author, and an Act of Parliament obtained, dated 17th August, 1916, known as "The Conway and Colwyn Bay Joint Water Supply Board Act, 1916," confirming the agreement entered into and authorising the construction of a dam, and the taking of water by the Conway and Colwyn Bay Joint Water Supply Board and the Aluminium Corporation Limited, for power purposes, the costs of obtaining the Act being paid for by the Corporation.

NEW DAM IN COURSE OF CONSTRUCTION.

The Dam is being formed of earthwork with an inner core of Portland cement concrete carried down into impervious strata. The total length of the dam is about 450 yards, its maximum width at the base is 72 yards, the maximum height above original ground level is 45 feet, and the greatest depth of the core wall below original ground level is 50 feet.

A satisfactory foundation has been secured, consisting of either solid rock or stiff blue clay, the rock extending for the greater portion on the Southerly side of the Cowlyd stream, the strata at the deepest point being good stiff blue clay.

The concrete core wall, for the full depth of the excavations, varies in thickness from 4 feet 6 inches at the bottom to 6 feet 6 inches at solid ground level, at which level the concrete is reduced to 5 feet 6 inches in thickness. At this thickness it is carried to 1,176 feet above Ordnance datum and then to a height of 1,206 feet above Ordnance datum, the thickness of the concrete being reduced by battering on both sides to 2 feet 6 inches at the top. The core wall is reinforced by steel rods $\frac{1}{2}$ -inch diameter, 2 feet apart vertically, 4 feet apart horizontally, from 6 feet below solid ground level, both sides of wall and 4 inches from the face of wall, to 6 feet from the top, with stirrup bars 4 feet each way. The spillway—160 feet wide, 1,206 feet above Ordnance datum—which is constructed entirely of concrete, has a foundation of solid rock, and so has the channel leading from the same for a distance clear of the toe of the dam, from which point the over-flow will be carried to the Cowlyd stream by means of a new cut.

A rectangular concrete tunnel with semi-circular roof, 11 feet wide by 10 feet 6 inches high, has been constructed through the dam for the purpose of conveying the outlet pipes, &c., of the Water Board and Corporation. The tunnel has been constructed on the line and at the level of the existing 24-inch internal diameter main of the Board, and provision has been made for the laying of another 24-inch

internal diameter main in the tunnel at some future date by the Board, and for a 4 feet internal diameter outlet pipe for the Aluminium Corporation. The concrete work of the tunnel where it passes through the core wall is reinforced, and the aggregate of all concrete is 5 to 1.

The material used in the filling for the dam is obtained from the side of the mountain just above the level of the top of the dam, and before any filling was commenced the whole of the peat (approximately 20,000 cubic yards) was removed from the surface of the site. The inner slope of the dam will be $2\frac{1}{2}$ to 1 with 15-inch stone pitching fixed on edge, and the outer slope 2 to 1 sodded or seeded. The top of the dam, which will be 15 feet wide, will have a rubble stone storm wall built on top of the concrete core to a height of 1,211 feet above Ordnance datum.

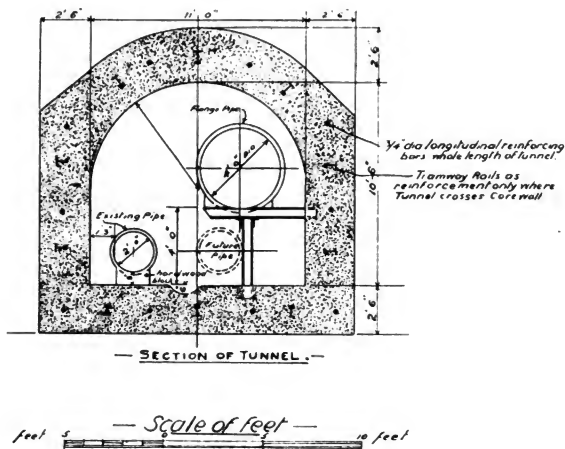


FIG. 3.

The stone for the concrete is obtained from the hill side about 200 feet above the works, and is a very hard grey granite. The sand used is granite dust crushed on the site. The stone is quarried by means of Ingersoll drilling machines, worked by compressed air, generated by electricity. It is crushed at the quarry by electrically driven stone crushers and brought down to the concrete mixing platform just above the level of the top of the dam by means of a



FIG. 4.—General View of Works.

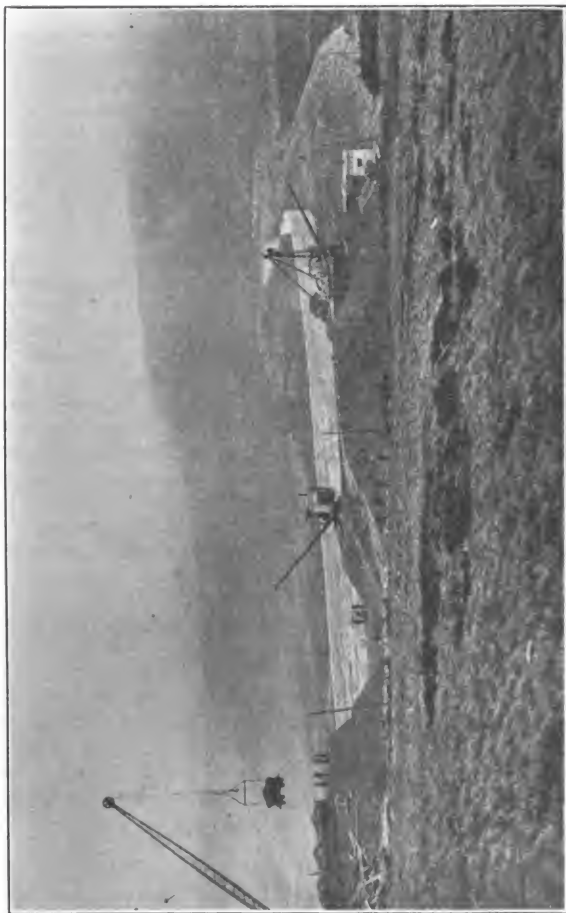


FIG. 5.—Dam in course of Construction.

counter-balance haulage drum. The concrete is mixed by means of two Ransome concrete mixers, 1 cubic yard capacity each, and these as well as a 9-foot sand pan are driven electrically. From the concrete mixers the concrete is taken to the dam in 1 cubic yard skips worked by an electrically driven haulage winch. The supply of electricity is obtained from the Cwm Dyli Power Works, situate at the foot of Snowdon, whose transmission line passes through the Cowlyd Valley, a transformer reducing the voltage from 20,000 to 440 for use at the works.

The earth filling for the dam is excavated by means of a 20-ton Ruston and Procter's Steam Navy, and is conveyed to the dam in wagons (each having a capacity of 4 cubic yards), by means of locomotives and steam haulage winches. At the site of the dam these wagons are lifted intact by a 15-ton Henderson Derrick having an 80-foot jib, by means of which the material is placed in position in the bank. The average filling up to the present time works out at 3,200 cubic yards per week (on a 10-hour day basis) the maximum amount put in in one week being 4,000 cubic yards. The total earth filling required is approximately 120,000 cubic yards.

Cowlyd Lake is very difficult of access, the only road leading up to it being from Trefriw, and as this road was a very poor one, and very precipitous in parts, it was necessary to provide means for conveying the necessary plant, portland cement, &c., to the site, and a 2-feet gauge works railway had to be constructed for a distance of about 3 miles from the top of the existing incline belonging to the Aluminium Corporation, which leads from the works to a point near to the concentration reservoir.

The plant, &c., is delivered at the Dolgarrog railway station by the L. & N. W. Railway Company, from which station the Railway Company's trucks are taken by the Aluminium Corporation locomotives over their railway to the foot of the incline, up which the whole of the plant and cement, &c., has to be conveyed. This incline has a lift of about 825 feet in 700 yards distance, the gauge is 2 feet and the trucks are hauled up by steam power. From the top of this incline the plant, &c., is conveyed along the works railway to the site of the dam.

ARRANGEMENTS FOR DRAWING OFF THE WATERS.

A new 5-foot internal diameter cast-iron water tower has been provided for in the new dam for the use of the Board, having outlets controlled by sluice valves at 1,169, 1,178·25, 1,187·50 and 1,196·75

feet above Ordnance datum, for the purpose of drawing the top waters for the supply to the district. This water tower is connected to the original 24-inch internal diameter main inside the tunnel, and the supply to the district will be controlled from this standpost and connection until the level of the water in the lake falls to a level approaching the present level of the lake, when water will be delivered from the existing outlet (1,156 feet above Ordnance datum). This outlet will be retained and controlled by a 24-inch valve which has been fixed on the main inside the tunnel. A valve house is allowed for on the water tower and this will be approached by means of a lattice girder gangway from the top of the dam.

The Aluminium Corporation outlet pipe, 4 feet internal diameter, the invert of which is 1,169 feet above Ordnance datum, will be controlled from a concrete water tower constructed at the end of the tunnel.

Under this arrangement the 13 feet of water in the lake below 1,169 feet above Ordnance datum, will be for the sole use of the Board, the remaining 37 feet, up to 1,206 feet above Ordnance datum, being for the joint use of the Corporation and the Board. The total capacity of the new lake will be 3,110,000,000 gallons.

The scheme is being carried out under the supervision of the Consulting Engineers to the Aluminium Corporation, Sir Douglas Fox and Partners, and the Author, the Contractors being Sir Robert McAlpine & Sons, and it is hoped that the work will be completed during the coming Summer.

The Paper was accompanied by plans and two photographs of the works at present in course of construction, which are reproduced as illustrations in the text, and the works were further explained at the meeting by means of a cartoon and other photographs. •

DISCUSSION.

The President

The PRESIDENT said that it was very refreshing to meet a civil engineer who was actually engaged in these hard times in carrying out works such as those described in the paper, and when they got an engineer who was carrying out works of that character at the present time to give an account of the scheme he was responsible for, he thought that they were to be congratulated. The author had very cleverly compressed the subject matter of his paper and had given them a running commentary from which he had picked out all the material points. The point that impressed him most about the paper were the very excellent terms which the author had arranged with the Aluminium Corporation. It seemed to him that the author was in the fortunate position of engineer to a Water Board which had persuaded another party to come in and carry out all the works that they required for their own purposes, free of cost to themselves, also to pay the expenses of obtaining the necessary Act of Parliament, and to undertake to maintain the waterworks for all time. He could not see that the Colwyn Bay Water Board had been put to any expense in the matter. If that was not a good piece of engineering he did not know what was.

One was apt to misunderstand the figures on page 218 regarding the amount of compensation water. It was mentioned there that compensation water was just over 1,500,000 gallons per day of 12 hours with a provision for cattle on the seventh day. That, of course, sounded very much more than it really was; he did not know what provision cattle required on the Sabbath, but if they knocked off whatever that might be, the compensation worked out at about 665,000 gallons per day of 24 hours, and they particularly wanted to note that, because, on page 220, the author gave two figures which were apt to be misleading. The first was the figure for compensation of 1,552,500 gallons per day, followed by "the total run-off from the watershed being 4,092,000 gallons per day." That, he took it, was a day of 24 hours. At first blush that seemed to indicate that the compensation was getting towards half the total available quantity, but really, if they took it at the proper figure, which was made quite plain on page 218, it was only one-sixth, which was more the normal figure. He was going to ask the author whether the figure he gave for the total run-off on the

watershed, something over 4,000,000 gallons per day, was the reliable yield on a period of dry years. He gathered that it was so, because he had made a rough calculation, taking the average rainfall, less one-fifth, to arrive at the fall in three dry years. That fifth was 15 inches, leaving about 75 inches. He then deducted 12 inches for absorption and evaporation, which left about 63 inches available. That worked out to an available yield of just over 4,000,000 gallons per day, which agreed very closely with the figure given in the paper. This figure, he took it, was ascertained by actual gauging. Probably in that rough calculation one should also make allowance for evaporation from the surface of the water.

With regard to the dam, nobody had said very much about it, but it really was something new in English practice. In America, the dam with a concrete core was a very common form of construction, but there, as a rule, the retaining banks on each side of the core wall were made of gravel instead of earth. He thought that the saving factor about this concrete core of the author's was undoubtedly his steel reinforcement. He did not think that the author would have considered a core of those dimensions without the reinforcement. The author had not mentioned in the paper, but in his remarks he referred to the manner in which the banks were being formed, by dropping the contents of the four yard wagons from a considerable height. Well, it was rather novel, one would not like to form a very definite opinion as to the soundness of such methods without actually seeing the work, but it sounded rather revolutionary to one who had been brought up in the theory that one should always spread the material, of which a bank was formed, in thin layers and take every precaution to consolidate it thoroughly by rolling or slewing the wagon road carrying the material on to the embankment. He could quite imagine the actual spot where the wagon load was dropped was made very solid, but one might hesitate a little as to whether they got uniform consolidation. Of course he had not seen it and one would like to know whether such a form of construction gave satisfactory results, because, obviously, it must be a cheaper method than spreading the material in thin layers and consolidating it.

With a concrete core, it was obviously of the utmost importance that the bank, particularly that portion which lay behind the core wall, should be absolutely solid and up to its work. That was to say, from the start actively supporting the concrete core which acted merely as a water-tight diaphragm to hold the water up, but it would not do that unless it was in its turn solidly supported. It was obvious that unless

The President the supporting embankment was in close contact with the wall and actually taking the weight that might be brought upon the concrete core, something might go. It was not like a clay puddle core, that had a certain amount of elasticity, or at any rate the power to accommodate itself. The concrete was rigid and must have its support without being called upon to lean back a little on the bank. One was therefore very interested to hear of methods of construction that had been adopted and anxious to see how it turned out. He wished to congratulate the author upon the very interesting and concise way in which he had described those important works, and he asked them to accord a hearty vote of thanks to the author for his very valuable paper.

Mr. Needham Mr. C. A. NEEDHAM remarked that he had listened with great interest to the elucidation of the paper by the author, and as one who was engaged in similar work it was, of course, particularly interesting. He was fully in agreement with the observations which the President had addressed to them, regarding the very advantageous position in which the Water Board was placed at, if one might say so, the Corporation's expense.

To him the most outstanding features of the scheme and the ones of which many water authorities might well be envious, were the natural advantages of Llyn Cowlyd as a reservoir for an upland gravitation scheme. Apparently all the fundamental necessities for the economical construction of such works were present on this site. With a top water level of 1,169 feet above Ordnance datum and impounding seven hundred million gallons with a dam only 176 yards in length and holding up only 13 feet of water, the conditions were ideal.

The new dam by which the top water level was to be raised another 37 feet also appeared to be most fortunate in its location, and as far as one was able to judge, it did not appear that they were likely to be troubled with the construction of wing trenches or other such extensive and expensive works that were at times sprung upon one, when the water was rising in the reservoir and new feeders to the river made their unexpected appearance in the valley below the dam.

Looking at Fig. 1 the precipitous nature of the ground was very apparent, particularly when the comparatively small increase in the top water level corresponding to a rise of 37 feet was noticed; he thought that this was unique, at any rate in this country. The principal accruing advantage of this small increased area of submerged ground was the saving in cost of stripping off the peat, which course had now, in the light of experience gained, been considered a

necessity. What this might amount to might be best understood, when it was found necessary in the case of the Alwen Reservoir for the Birkenhead Waterworks to excavate and remove entirely from the gathering ground over one million cubic yards of peat. Mr. Needham

With regard to the action taken by the author in January, 1916, by which $\frac{3}{4}$ -million gallons per day were added for use instead of going to waste at the overflow tank, it had been Mr. Needham's opinion for some time that active measures should be taken to reduce the total quantity of water required by any particular town or community, by cutting out all waste and what one might call needless extravagance of water, and in such way either obviate or postpone for a considerable time the necessity for embarking upon comprehensive schemes for the provision of additional supplies.

It had been recognised that the available sites in this country, suitable for the construction of such works at any cost within reason, were comparatively few, and these were being rapidly seized upon by the larger and more wealthy towns, and the prospects for independent supplies to the smaller ones were not by any means promising. Hence it was that Parliament was now, more than formerly, requiring the promoters of all such schemes to supply in bulk, on reasonable terms, any authority located within a certain distance of the pipeline or aqueduct throughout its full length and the saving of every possible thousand gallons was necessary, if these obligations were to be successfully fulfilled.

He had noticed a tendency in this direction during the recent Ministry of Health inquiry at Southport, in which the Inspector, going into the figures, stated that he thought that the consumption of 35 gallons per head per day was unduly high. Mr. Needham did not know that this was an unduly high figure, as he was not in the position to say what proportion of this was due to trade consumption, but it was apparent that the governing authorities were taking this question seriously in hand and he should think that in future schemes, when promoters came seeking powers for taking up water and constructing expensive works, particularly for town supplies, the first thing that the promoters would have to give an account of, would be as to what use they were making of the water which they already had.

The various provisions under heads of agreement as to the financing and operation of the new Cowlyd scheme appeared to be somewhat involved, and questions of dual control in operation loomed rather large, at least that was the impression given as one read, but possibly these conditions would not prove so onerous once the points of

Mr. Needham roughness had been smoothed down during the first year or so of working.

Mr. Ward Mr. H. B. WARD thought that the paper was a very practical one, and the first point which he desired to refer to was the use of these stoneware pipes. He would like to know the exact reason for their adoption in the first instance, as perhaps in years to come they would want something better, obviously they were very cheap. Owing to pressure difficulties they could not be considered quite satisfactory at the present time. He was also struck with the tremendous powers held by the Aluminium Corporation in regard to their ability to use water from their own watershed, and from almost any other watershed in the neighbourhood. He wondered whether other districts had anything to say in the matter, or whether the Aluminium Corporation had quite a blank cheque to make a "corner" in water, possibly to the detriment of other districts which might perhaps regard the area as one to which they could go to draw their supplies. He would be interested to hear why the dam was arched on plan, as though an arched dam was very strong when of masonry or concrete, he doubted whether they got increase of strength and a genuine arching effect in an earth dam.

Mr. Duncanson Mr. A. W. DUNCANSON asked if it was a fact, that in the second instalment of the scheme, the pipe track was laid on the East side of the river to avoid the cost of a bridge over the river.

Another point was the question as to the position of the rain gauges on the watershed area, from which was taken the mean annual rainfall. Perhaps the author would indicate on the plan where those gauges were fixed, and if he could also say what elevation each gauge had, it would be very interesting. Another point that struck him was that the Board seemed to have got the right end of the lake to work with when drought came, namely, the bottom and water end.

The Author The AUTHOR, in reply, said that he desired to thank the Society sincerely for the honour that had been conferred upon him by inviting him to read the paper, and for the way in which it had been received. He had tried to interest them, and was glad to realize from the reception of the paper that he had succeeded in doing so.

He was rather inclined to agree with Mr. Needham that 35 gallons per head per day was ample, and that 30 gallons was quite a good supply. In his own district during the Winter nearly twice that amount was used per head per day, and in the Summer, although there was a considerable increase in the population, not much more water was used, and the supply came down to 30 to 35 gallons per head

per day. The night lines of the meters showed considerable waste, and he quite agreed that at any Inquiry of the Ministry of Health the question of consumption per head per day, should be seriously considered.

Regarding the use of earthenware pipes from the gauge chamber to the overflow tank, the position at the time the original works were constructed, was that the Joint Board was not strong enough financially to lay cast-iron pipes, or this would have been done, the earthenware pipes being put in on account of the temporary saving in cost.

He was rather pleased that the point had been raised as to why the dam had been built on a curve. In the original scheme a concrete dam was designed, but owing to the difficulty of getting cement and transport during the War, it was decided to abandon the concrete dam, and to put in a concrete core and earthwork dam, as there was excellent filling adjoining the site. As the major part of the trench had already been excavated for the concrete dam, it was decided to continue with the new construction on the curve. The curve in his opinion would add a great deal of strength to the dam, and possibly minimize some of the anticipated dangers referred to by the President.

When the filling was tipped into the bank in dry weather, water was kept continually running on to it, in order to consolidate it further, and up to the present he had not noticed any settlement. The tipping of the filling in this manner was certainly a new venture, and he agreed with the President that it departed from the usual practice, but with the very excellent filling available he did not anticipate any trouble.

The four rain gauges from which the average rainfall was taken were situated on the Watershed at heights of 1,168, 1,700 and 1,900 feet above Ordnance datum, and were fixed under the direction of Dr. Mill in 1908, who in that year made an estimate of 90 inches, based on one rain gauge which had been fixed for some years near the existing dam at a height of 1,168 feet above Ordnance datum, and from statistics in his possession. It was interesting that daily readings of the gauges taken since 1908, confirmed the estimate made by Dr. Mill.

He quite agreed with the remarks about the happy position of the Water Board.

Regarding the point raised by the President as to the run-off from the Watershed, the amount of 4,092,000 gallons per day, was based on the average annual rainfall of 90 inches, less $\frac{1}{3}$ -th for the average three dry years, and an evaporation of 12 inches which gave an available annual rainfall of 60 inches on a watershed of 1,100 acres.

The Author The compensation water of 1,552,500 gallons given on page 218 was delivered during a period of 12 working hours out of each day, for six days of the week, and sufficient water for cattle on the seventh day, and represented 1,330,700 gallons per day when taken over a full week, provided the small quantity required for cattle on Sunday was not taken into consideration. Further, it meant that the Water Board had to manipulate valves each morning and evening as well as on Sundays.

The compensation water, 1,552,500 gallons per day (under the 1908 Act) given on page 220 was delivered during every day of 24 hours, being an increase of 221,800 gallons per day of 24 hours over the original compensation water, 1,330,700 gallons, and represented 38 per cent. of the available run-off.

16th March, 1921.

W. BRODIE, M. Inst. C.E., Past President,
in the Chair.

The Council reported that the following elections had been made :—
ROBERT ASKEW ABRAHAM, B. Eng. (*L'pool*), and ANDREW DALL, as *Members*;
THOMAS GEORGE GARFORTH, as *Associate Member*; JOHN FRANK BICKERTON,
THOMAS CALDWELL, HENRY COLLIN, WILLIAM JAMES FERGUSON and
DAVID LLOYD, as *Students*.

“General Remarks on Practical Merchant Ship Construction and Repairs.”

BY GEO. LAIRD LYLE, M. Inst. N.A.

So many papers on scientific and theoretical subjects have been read before this and kindred institutions that it occurred to the author that a paper almost wholly dealing with practical matters would be of interest, and for his subject he has taken the above title.

LOFT AND SHIPWRIGHT DEPARTMENTS.

Loft work to-day forms a very important part in shipyards and a good loftsmen is indispensable to any firm, particularly where templated and batten work are largely carried out. As time goes on, these methods will, no doubt, become universal. Just think of the time, not so many years ago, when plates were templated from the vessel plate by plate, truly a slow method; nevertheless, a vessel in those days was constructed and completed in as short a time as a similar vessel would be under present conditions. There can be no reasonable excuse for this as machinery has improved, shipyard arrangements for quick output have been made much better, and with templates and battens all prepared, long ere the material is required, vast quantities of plates and sections can be prepared ready for erecting, and with up-to-date overhead cranes and gantries in most of the shipyards, the former time of construction should be halved, despite the fact that a 47-hour week is worked instead of a 54 as formerly.

In template making, only well seasoned wood or a specially

prepared paper (sample of which is here and may be examined) should be used, and at all times should be kept in a covered space at a moderate temperature. Wood templates are liable to shrink or warp, and if marking of material takes place after this has occurred, nothing but faulty work can follow.

If multiple or automatic punches are used, work must either be good or very bad, the smallest measurement off the mark is liable to affect a large area.

When work from templates or battens commences to be placed in position on the ship, one part of the vessel (usually amidships) must be properly plumbed, raked and horned, so as to give a correct starting point for all plates and sections, as all material must be very accurately placed. If extreme care is not observed at this stage, trouble begins at once, a small mistake in placing at first, compounds itself before the end of the vessel is reached. Material properly placed, cuts out the use of ribbands and shores and thereby the ship automatically fairs herself.

In templated work to fit edgewise, such as tank intercostal plates, it is customary when fitting these to leave out one in every 12 or 15, as there is always a tendency to gain in length. After the intercostal plates are in position, in lots of 12 to 15, the ones left out are then placed. Some firms, the author believes, make the templates for these plates $\frac{1}{16}$ -th of an inch shorter than the required length, and by adopting this method they find, when erecting, that the edge left by the plate shears leaves the plate the exact length, therefore an occasional intercostal does not require to be temporarily omitted.

It is thought by many that bars of long lengths (say 40 or 50 feet) stretch in the punching, thereby making template work on long sections somewhat uncertain, but it has been found that no stretching takes place in punching.

In making templates or battens for deck plates, allowance must be made for the round of beam, as the plate travels round a greater radius than the beam, a stretch allowance of $\frac{1}{8}$ -th of an inch in 8 feet being given so that the holes will be perfectly fair with those of the beam. If the stretch allowance was not made, consider what would happen. In the case of a vessel of 56 feet beam and deck camber of 14 inches, assuming the holes at the centre line are fair, the holes connecting the deck stringer plate to the beam at the ship's side would be unfair to the extent of $\frac{7}{16}$ -th of an inch.

With multiple punched work, all holes are punched from one side of the plate, and this is not the faying surface in all cases. (In

ordinary punched work, plates have frequently to be turned, some holes being punched from one side and some from the other), therefore good conditioned punches and dies must be used to avoid rags on holes. Take shell plating for an example, it is customary to punch all the plates from one side. This being so, the plates on the port side of the vessel are countersunk from the side the holes are punched from and the starboard plates from the opposite side or vice versa.

A plate of 28 feet by 6 feet by .50 can be punched and sheared at a multiple machine in about 10 minutes, another 7 or 8 minutes is necessary to fix it in position for punching, the total time taken to finish this plate being approximately 20 minutes. To prepare and punch such a plate at an ordinary machine would take about $1\frac{1}{2}$ hours, and in addition to the extra time, unfair holes are liable to be met

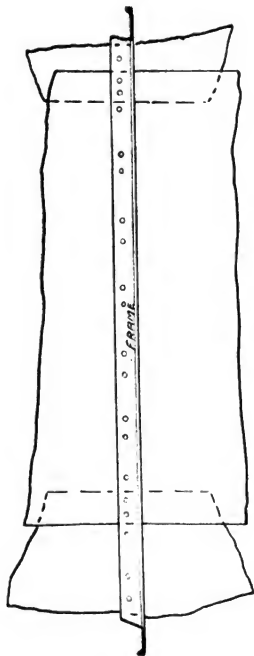


FIG. 1.

with in this method. The number of men employed in the former method is 3, and in the latter 7.

There is also the automatic punch for sections—a bar is placed on rollers and fastened at ends by a screw arrangement, the section then travels along without any manual assistance and the holes are punched. The number of men employed is 3, against 5 at an ordinary angle punch.

Of course any spacing of holes cannot be adopted at a few minutes notice, but standard spacing is used, the spacing of the rivets in the overlaps of plates being the basis of standard, as the overlap spacing differs from frame spacing, the latter being greater; the difficulty is got over by arranging the frame holes as shown in Fig. 1. Another method of getting over the spacing difficulty is to adopt the frame hole spacing and put in intermediate holes in each row in overlaps.

Of recent years an arrangement has been fitted to the multiple punch which enables the plate to be sheared at the same time as the punching is being done.

Up till a few years ago multiple punched work was confined to flat areas, but now an arrangement can be attached to the machine which enables plates with considerable sheer and shape to be punched, the basis of working this arrangement is obtained from the scribe board.

In fairing a vessel on the stocks, good shipwrights are invaluable, for frequently a sagging takes place here and there, probably caused by the ground slightly yielding or by heavy weights such as plates being placed on top. During construction, and particularly with extensive template work, it is imperative that the bottom of the vessel be kept as straight as possible.

If templates are to be made from the vessel, a considerable amount of fairing, plumbing, raking and horning is necessary, and also the use of ribbands. In the forward and after bodies, if a frame is the slightest bit too far forward or aft, a fullness or leanness exists and makes an unfair shell.

Perhaps the author should state here that in several continental yards a large quantity of material is marked from ordinary battens, necessary particulars for these battens being taken from the waterlines and buttocks shown on the scribe board. The worker, instead of marking the holes of the material with paint from a round pin, marks with a fine chalk pencil, then centre punches the hole, a corresponding nipple is made on the punch, the punchman places the punch nipple into the mark on the plate and then punches; this method ensures fair holes but is a slow process.

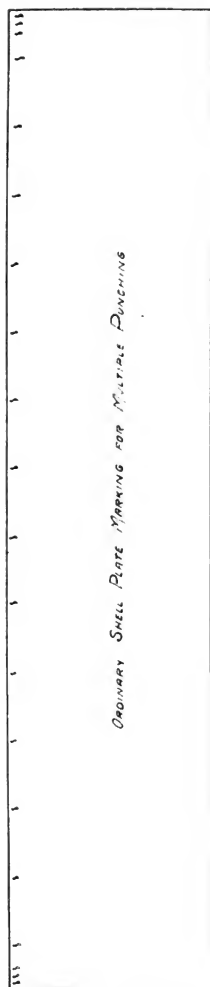


FIG. 2.

British builders adopt marking from battens for multiple work with chalk marking ; Fig. 2 shows the marking necessary for punching a shell plate at a multiple machine, it is very simple and takes little time in comparison with the old way of marking every hole.

In erecting work from template marking, the greatest care must be taken to ensure that the margin connections and beam knees fit at proper heights. It is not prudent to attempt to prepare plates which have considerable sheer and twist at the extreme stern of the vessel from the template or batten method.

On paper, it appears as if the adoption of multiple or automatic punching machines should greatly reduce the time of construction, but this does not always follow in practice. Another question which may be asked is : "Do the builders receive sufficient reduction in cost of labour to compensate them for installing these expensive machines." If the construction period is not reduced and if the builders receive insufficient compensation for the installation of these machines, they can hardly be blamed for lack of enterprise in not adopting them.

In constructing floating docks, the batten method and multiple punching is ideal, but how many floating docks or vessels of similar design are built ?

PLATING DEPARTMENT.

Plating is one of the principal departments of any shipyard, for much depends on good plating work. If it is good, all that follows it is usually good.

It is not intended in this paper to go into every detail of this section, but just to single out parts which may be of interest.

With the introduction of templated and batten methods and of multiple and automatic machines the tendency towards bad workmanship is lessened.

Among the first things the plater must take care of are, that all punches, dies and shears of machines are kept in good order, for if not, they are the first cause of trouble. If a punch or a die be badly worn or ill fitting, a rag or burr is left on one side of the punched hole. If shears are worn or ill fitting, a rag is left on the sheared edge of the plate, and if riveters are asked to fit rivet heads against large rags on holes, the rivet has little chance of being right up, this is also one cause of rivet heads splitting. If the centre plate of three plates fitted together is punched with rags left on the holes it can never be closely riveted to the outside plates.

Some of the Members present who have had the misfortune, like

the author, to crawl through and examine double-bottom tanks occasionally, must appreciate the difference of crawling through clean-cut manholes from ragged edged ones, particularly when going from the side of the floors the rags are on.

If templates for material are made from the ship, great care must be taken to see that all adjoining work is properly in position before they are made; much skill is required for this work. Packing out of templates is required at places according to required shape, such as bilge, ends of keel, boss, oter and forefoot plates. The ordinary plater is seldom entrusted with these parts, but an experienced man is generally available.

The bevelling of sections—and this is considerable when the bow and stern formations of a vessel are considered—often does not receive the attention it ought, unless bevelling machines are used. When these machines are used they are placed convenient to the frame furnace door, and as the frame is taken hot from the furnace it passes through the bevelling machine and is set to the necessary bevel. For example, take several parts of the vessel and see what happens. Of course all present know that the shell frames in the fore body look aft and in the after body look forward, so that an open bevel is obtained to admit of better workmanship and easier working. Consider the bevelling of the extreme forward frames and extreme after frames. Sometimes they are found like Fig. 3, with a hollow in the shell flange through careless workmanship. When excessive open bevels occur it is always advisable to dress the shell flange with a chisel, so that the shell plate will lie flat to the frame; if this is not done, the shell plate is usually drawn to the flange, and it looks and

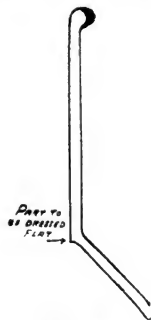


FIG. 3.

is, very bad, and still worse if the vessel's hull in way be painted black and the sun's rays strike the point in question.

In a deck with considerable sheer, the deck flange of the beams should be bevelled in way of the sheer, otherwise the deck when plated and riveted would be like this Fig 4.



FIG. 4.

The bevelling of the frames in way of bilge, where the bilge formation dies off from the mid-ship section, is another place where defective bevelling is met with.

Attention must be given to all furnaced work ; frequently with frame sections, sufficient is not allowed for draw and spring caused by cooling, and if the section be large it is extremely difficult entirely to rectify this when the frame is cold and being tested on the frame line of the scribe board.

If the frame be joggled, the joggling calls for careful attention both in depth and in not making it too sharp, lest it fractures the frame. (The same trouble is liable to occur in joggling plates). All joggling by machine is done when material is cold.

Joggling of the reverse frames in all tanks is very desirable, as it affords a good method of ventilation, each space having an air passage at every joggle, and if suitable air pipes or vents are fitted to tanks a good circulation of air follows.

While on the subject of tanks it should be mentioned perhaps that more efficient arrangements might be made in the bottom of tank floors, so that better drainage could be obtained. This is an important factor, for many vessels to-day carry many tons of unpumpable water when the tanks are stated to be empty. A moderate estimate of water in a tank stated to be pumped empty is 1 inch to $1\frac{1}{2}$ inches, and this over a big area means the shutting out of a considerable quantity of cargo ; in a vessel of, say, 8,000 tons, 30 tons might be taken as an approximate estimate.

Plates are sometimes marked and punched when in a buckled shape and afterwards rolled or mangled straight. This sometimes affects the fairness of rivet holes.

There is ample scope for improvements and suggestions to save cost in the plating department of many shipyards.

In light plating it is not helpful to work with a corresponding small hole, for there is a limit to practical working, the smaller the holes worked the higher the percentage of unfairness becomes, and the largest sized holes within reason permissible in light plating should be used.

Furnaced plates such as keel shoe plates, boss and oter plates are often made very hard and brittle with frequent heatings, and there is no reason when this takes place why they should not be annealed.

Wherever possible furnaced plates should be dispensed with, and with skilful arranging of overlaps and landings the minimum of furnaced work can be arrived at. In some instances it is often better to work with two small plates than struggle with a large one; for the latter, if of awkward formation, will be the more costly and take up more time.

In parts of a vessel where Lloyd's riveting tables do not specify certain spacing of rivets, unfortunately they are sometimes spaced well over what might be termed a maximum spacing. Bunkers suffer most in this respect. They are subject to very varying temperatures and moisture, yet sometimes very wide spacing of bunker riveting is found, with the result that in a few years corrosion sets in quickly between the seams, rivets become rust drawn, and at an early date renewals are necessary.

In many vessels too few manholes are fitted in tank tops. There is no reason why many more should not be fitted, and when the vessel is building is the time to fit them. Manholes should never be in floors directly under pillars and other important supports.

In vessels building or under repair, access holes should be cut in bulkheads between stiffeners, wherever necessary, for convenience of workers, and saving of time usually occupied in climbing and descending ladders when going from hold to hold. On completion of work, riveted plates should be fitted over these holes.

If deckhouses and casings are plated with horizontal plating, the sighting edges of seams should look downwards, as any unfairness is not observed if seams be so arranged. If seams look upwards it is difficult to make and keep them fair.

Joggling of deck or tank top plates should be avoided, as wastage sets in rapidly in way of the joggle, owing to it forming a lodgment for water. To joggle sections in lieu of plates is preferable. Joggling of material reduces cost, it saves the fitting of liners, and reduces weight, whilst riveting costs are reduced, as an allowance is made in riveting

prices owing to no liners being fitted. Joggling machines are now made to joggle any section used in shipbuilding.

Trimming hatches should be fitted in all vessels likely to trade to Bristol Channel ports, so as to avoid delay at these ports. Particulars of necessary trimming holes can be obtained from a circular issued by the Board of Trade.

All odd work should be placed in position with the general work, the missing of small items runs up costs surprisingly quickly, and those who have charge of departments will do well to give close attention to odd work.

The costly formation of masts might be altered with advantage, and as regards this a mast of the section as shown in Fig. 5, and derricks as shown in Fig. 6, all machine riveted, are suggested. Costly smithwork could be dispensed with, all derrick tables, masts, stays, derrick spans, &c., could be fastened to the flanges. If repairs were necessary at any time, plates could be dealt with, with masts in position.

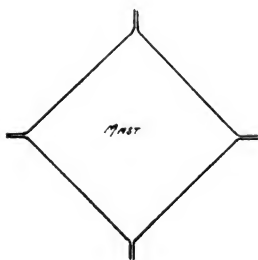


FIG. 5.

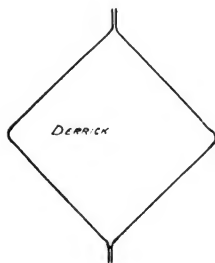


FIG. 6.

The values claimed for flanged plates are sometime doubtful, owing to the difficulty in arriving at accurate fitting. Material draws considerably in way of flanges, and although it may be of cold flanging quality (26 to 30 tons tensile), if particular attention is not given to file to a round the rag edge of plate left by the shears, fractures may be very numerous. If flanging be done in frosty weather with plates at a low temperature, fractures frequently occur. To avoid such fractures the extreme cold temperature should be taken from the plate.

There are several parts of a vessel, where to adopt flanging in lieu of angles is an advantage, such as tank margin (top only) garboard plates to vertical bar keels, stiffening edge of bracket plates, &c.

Many vessels have been fitted with margin plates flanged top and bottom, but owing to the continually changing form along the margin, bottom flanging is difficult to fit to the shell and in way of margin overlaps. At one end of the plate a different flange radius from the other is necessary; the only saving attained by this method is the caulking and rivets, this saving does not cover the additional expense of fitting. Little or no material is saved by adopting flanging, as when a flange takes the place of an angle it must have an equivalent flat surface to the angle, for example, 5 inches of plate is required to leave a 3-inch flat surface in way of flange.

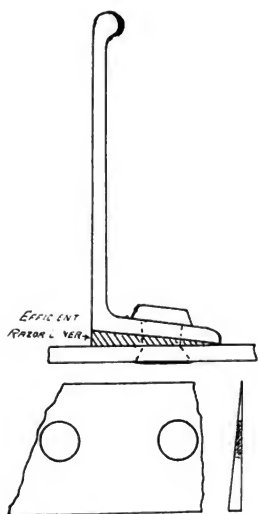


FIG. 7.

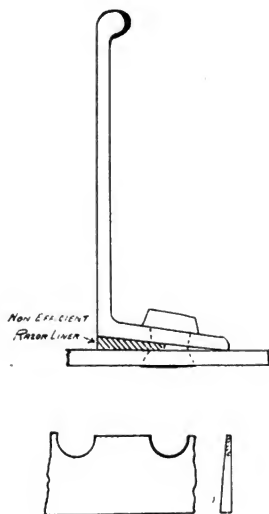


FIG. 8.

Packing pieces or liners are necessary in construction of ships owing to overlap work; the vacancy filled by a liner should be taken up with one piece of material properly fitted, and tapered if necessary. Sometimes the thickness of liners required is excessive, and when this is the case, something requires mending; two thicknesses are occasionally fitted but should not be adopted.

It may be necessary to fit razor-shaped liners where bars (especially heavy) are somewhat off the bevel ; such liners should never be fitted unless they have full holes in them as per Fig. 7. The author has seen razor liners of the form shown in Fig. 8 fitted, but these are most unsatisfactory. A place where one may occasionally come across work of this description is in way of the frames to the bilge, in forward and after bodies from the point where the mid-ship section stops and the ship begins to taper to its bow and stern formation.

The author has known of cases where the heels of frames were not bearing on the shell plates after being riveted up, and to cover up this defect thin strips of sheet iron were caulked or hammered into the vacancy ; fortunately this is not a common practice.

In fitting liners, workmen sometimes punch 1-inch holes in liners for $\frac{7}{8}$ -inch riveted work and $\frac{5}{8}$ -inch for $\frac{3}{4}$ -inch, this ensures the easy entry of the rivet into the hole, and if the liner holes are a little unfair the liner moves somewhat to accommodate the rivet ; once the liner is in position the excessive size of the holes in it cannot be seen. The same method is sometimes adopted where 3 thicknesses of material—3 plates or 2 angles and 1 plate, or 2 plates and 1 angle (see Fig. 9) are riveted together, the centre thickness having the large holes. All holes in liners should be punched with a corresponding size of hole to that of the work in which they are fitted.

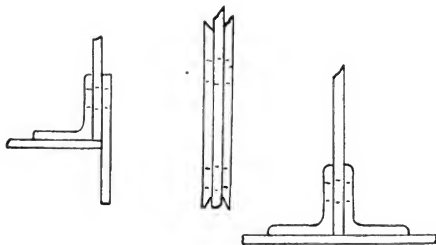


FIG. 9.

RIVETING DEPARTMENT.

There is a tendency to take too little time in preparing work for riveting, and one of the chief faults, if not the chief, is that the work is not sufficiently screwed together, too few bolts being used, and, as all know, if work is not efficiently screwed close, no matter how much

labour is expended on the rivets they can never be entirely satisfactory. When thicknesses are not properly close on riveting, a collar forms round the neck of the rivet and between the thicknesses and prevents them from adhering as they ought. More supervision might, with beneficial results, be given to the screwing up of all material before riveting.

Now that pneumatic riveting in many yards has largely taken the place of hand, efficient screwing up is needed more than ever, as no plying up of the seams clear of the rivets is done by the riveter, the labour being solely on the rivets.

With pneumatic riveting, several yards have been put to much inconvenience and expense by using iron rivets, and it has been found that steel rivets stand much better to the pneumatic tools, split and broken heads being largely the trouble.

Another faulty way of riveting is, instead of hammering the rivet right up until the hole is properly filled, to nobble it over to one side when it comes through the hole; and with artful hammering the author fears only the outside portion of the hole is filled, especially where three or four thicknesses are joined together and the holes in each thickness have been punched; if the centre thickness or thicknesses have been drilled instead of punched, or a smaller sized hole punched and afterwards rimmed to the required size, much better riveting conditions are obtained.

It is a question whether rivets are of too high tensile—25-30 tons—for the hammering up must have a tendency to make them hard and brittle. It would be interesting to see the results of tensile and bend tests carried out on a rivet before and after hammering.

A tool known as a "drift" is often used for fairing holes and is very detrimental. It tends to separate the closely bolted thicknesses, thereby causing the old complaint—a collar on the rivet between the thicknesses. It also makes one part of the hole oval shaped, which the rivet does not fill.

Another tool, known as a "foalsfoot or holecutter" is also used to cut a part of the hole should it be unfair, thus making the hole neither round, square, nor oval. The rivet can never fill this newly made formation, as usually the part of the hole cut by this tool is in the inner thickness and nearest the head of the rivet, and if rivets are heated, as in some districts, the part near the head is not always hot enough to allow it to swell to the new formation of the hole.

Another tool sometimes used by the riveters is known as the "tomahawk," used for dressing round the rivet point (frequently in watertight work). In medium and light work the author is of opinion this tool should not be used; it gives a nice finished appearance to the rivet, but has a tendency to cut deeply into the material.

There are two methods generally used for rivet heating, each district having its own practice (some firms use coal and others coke, for heating): one, to bury the rivets in the fire with their points nearest the blower, the other, to place a small plate with holes in it to suit the size of rivet used in the fire; rivets are then put into these holes with points facing the blower, and when considered hot enough are withdrawn and placed in the holes for riveting.

Discussion has frequently taken place as to the relative value of iron and steel rivets and their performances when closed by hand, hydraulically or pneumatically.

To obtain reliable information, Dr. Montgomerie, of Glasgow, at the request of the Committee of Lloyd's Register of Shipping, recently carried out experiments at Lloyd's Proving House, Glasgow, on treble and quadruple riveted joints.

A series of twelve specimen joints was made under ordinary conditions. Six treble riveted joints and six quadruple riveted joints were designed, the plating and riveting being taken from the Rules of Lloyd's Register.

The treble riveted joint was effected between plates $23\frac{1}{2}$ inches broad and 0.44-inch thick, and contained 27 rivets $\frac{3}{4}$ -inch in diameter. The quadruple riveted joints were formed between plates 17 inches in breadth by 0.58-inch in thickness, and contained 20 rivets $\frac{7}{8}$ -inch in diameter. The joints were numbered as set forth below:—

Mark	Type of Riveting					Material of Rivets
A 1 ...	Hydraulically Riveted	...	...	...	...	Iron
A 2 ...	Hydraulically Riveted	...	...	...	...	Steel
B 1 ...	Pneumatically Riveted	...	...	...	...	Iron
B 2 ...	Pneumatically Riveted	...	...	...	...	Steel
C 1 ...	Hand Riveted	...	...	...	...	Iron
C 2 ...	Hand Riveted	...	...	...	...	Steel

The plates were of ordinary shipbuilding quality.

The following Table gives these results:—

TREBLE RIVETED JOINTS.

Joint	Riveting and Rivets	Pull at which slip occurred	Breaking Load
A 1 ...	Hydraulic. Iron Rivets. Snap Heads and Points	Tons 95	178 Tons
A 2 ...	Hydraulic. Steel Rivets. Snap Heads and Points	92	At 180 Tons pull joint remained unbroken. Evidently on point of fracture
B 1 ...	Pneumatic. Iron Rivets. Snap Heads and Countersunk Points	92	170 Tons
B 2 ...	Pneumatic. Steel Rivets. Snap Heads and Countersunk Points	85	182 "
C 1 ...	Hand. Iron Rivets. Pan Heads and Countersunk Points ...	95	180 "
C 2 ...	Hand. Steel Rivets. Pan Heads and Countersunk Points ...	105	At 180 Tons pull joint did not break although much distorted

All fractures took place through line of non-countersunk holes, except in case of B 2.

So far as the breaking strain of the joint is concerned, no sensible distinction can be drawn between the efficiency of the various joints in respect of the method of riveting employed or the material of the rivets used.

QUADRUPLE RIVETED JOINTS.

Joint	Riveting and Rivets	Pull at which slip occurred	Breaking Load
A 1 ...	Hydraulic. Iron Rivets. Snap Heads and Points	Tons 95	Tons See below
A 2 ...	Hydraulic. Steel Rivets. Snap Heads and Points	85	170
B 1 ...	Pneumatic. Iron Rivets. Snap Heads and Countersunk Points	80	178.3
B 2 ...	Pneumatic. Steel Rivets. Snap Heads and Countersunk Points	88	See below
C 1 ...	Hand. Iron Rivets. Pan Heads and Countersunk Points ...	95	"
C 2 ...	Hand. Steel Rivets. Pan Heads and Countersunk Points ...	70	"

A 1, B 2, C 1, C 2, while they did not break, were greatly distorted and evidently on the point of fracture. The results of the series point to the conclusion that no sensible difference in ultimate strength exists as between the different methods of riveting and material of rivet used.

If holes are unfair after screwing up, they should be rimmed, and then recountersunk after rimming. Of course, if holes are much unfair, it either means rimming out a size larger, provided the material affords sufficient landing, or condemning the material.

The author has known some cases where countersunk headed rivets were used in ordinary punched work (without a countersink); this is a bad practice and should be avoided, as it is quite impossible for the rivet to fill the hole (see Fig. 10).



FIG. 10.

All rivets in watertight work should be hammered down from the outside of the compartment, so that if any leakages should occur they can be easily caulked up without emptying the compartment; all stiffening in way of water or oil-tested compartments should, whenever possible, be placed inside the compartment, for simplicity and ease in making watertight. When stiffeners are fitted on the outside, endless difficulty is sometimes met with in making them watertight and it may also mean emptying the compartments to make good any defects, and afterwards retesting. Three or more ply riveting in way of watertight work should be avoided wherever possible. Each yard has its own type of rivet for special parts, such as bilge keel shell connections, and weather deck stringer angles to shell. The best method for bilge keel shell riveting is to countersink the inner side of the bilge plate and fit countersunk headed rivets hammered down from the outside. As an additional precaution, the heads are also carefully set up. It will be noticed that the rivet connection of bilge keel shell angles or tee bars taking the bulb plate, is in every instance a stronger connection to the shell than to the bulb plate; this is so arranged that, should the bilge keel get damaged (and it frequently does), the outside rivets only would be affected and thereby enable the ship to carry on until a

suitable opportunity arose for doing repairs, the shell riveting meantime remaining intact.

CAULKING AND TANK TESTING.

This is a branch which oftens does not receive the attention it merits. It is very important that all caulking should be properly executed. Caulking of straightforward work is generally all right, but the parts coming in way of overlaps, joggles, liners, &c., are often not well executed. Butts are often not butts owing to their not being properly fitted edge to edge. One method adopted to get over this, although unsatisfactory, is, "thin plies" of iron are fitted into the unfilled space and only the sighting edge is tooled down; this when finished gives the appearance of good work. In way of overlaps the short tapered liners are sometimes not too well fitted, and if this be the case it means that iron or steel wedges are driven in, not filling up the vacancy but jamming at the caulking edge and then receiving the attention of the caulking tool. With vibration and working of the vessel these wedges have a tendency to loosen. Where sections are joggled in way of watertight bulkhead or compartment boundary angles, such as deck, ground or frame bars, it is impossible to joggle them (cold) to fit hard up to any plate. The joggle always leaves a space as shown in Fig. 11; this causes unsatisfactory work for the

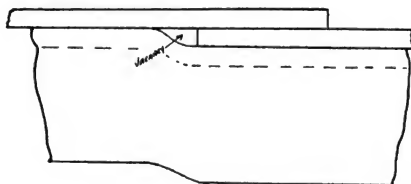


FIG. 11.

caulker—that of filling up with wedges. All joggled sections forming boundaries of watertight compartments should be joggled a 2-hole distance from the edges of the plates they cross, then a 2-hole liner suitably shaped should be fitted. Wooden wedges have been driven in in lieu of iron or steel, and these wood wedges have stood the pressure; needless to say they give out very quickly and may cause serious damage.

A very useful tool to all shipbuilders, ship repairers and engineers, is "The Putty Pump." It is usually put out of sight during inspection and testing of tanks, although frequently used in preparing the tank; surely it is quite a legitimate tool and need not be hidden, for it is a boon and a blessing to many, and often, to ensure absolute tightness, the pump must be used. The parts where it is necessary to use the pump are marked by an experienced man during a preliminary test, a hole is drilled and threaded through one thickness, this hole is made to fit the nozzle of the pump which is screwed at the end, the pump is fitted to the hole and the pumping of red lead, now superseded by Vulcan cement (ground whiting, litharge and boiled linseed oil), or other equivalent is proceeded with. The holes for these injections are easily seen by the surveyors when testing the tanks. For an example of putty pump work, consider a bulkhead with double angles right round. Water may get in and run along the space between the angles and eventually find some weak spot for an outlet; if the putty pump is judiciously used it will prevent this.

Where plate landings cross watertight compartment bulkheads, stoppers formed of special brown paper, steeped in boiled oil, varnished on both sides and smeared on one side with Vulcan cement are fitted, and here again the putty pump may occasionally come in useful; water under pressure may travel between plates or sections for several feet before it comes to sight. The fitting of stoppers usually prevents this. Tank margin plate crossings are always difficult parts to make watertight; if shell landings run continuous for any length in way of margins, stoppers, tap rivets, in addition to ordinary rivets have to be used; but the difficulty can be easily overcome by breaking the run of the shell landings as shown in Fig. 12.

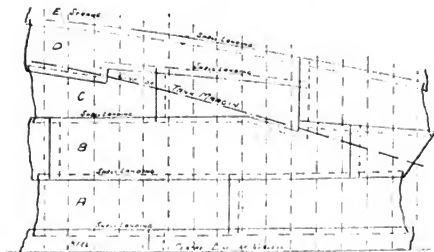


FIG. 12.

The uninitiated seeing a green tank having its first pressure of water might well wonder how it could ever be made watertight. No prudent manager would request the attendance of surveyors at a first test; if he does he courts trouble. It is advisable for those who have not seen a first test on a large tank, if they have the opportunity, to embrace it, and see what has to be made tight and how it is done.

In repair work, care should be taken to ensure that the old caulking is removed, to give every chance for the replaced plates to be efficiently caulked.

Great care should be taken with the caulking in way of scuppers of weather decks, where the stringer angle has been cut and a joint or compensating angle fitted under the stringer plate in way. It is often difficult to make this part efficiently watertight and this is never too satisfactory, owing to the poor connection afforded by the underdeck joint or compensating angle, especially where frame spacing is small, the frame space determining the length of joint or compensating angles.

ODDMENTS.

In building a vessel many people seem to forget that Lloyd's requirements are minimum requirements and that it would be beneficial to make slight increases at parts which in a few years time may require attention. When a vessel shows signs of wastage is not the time to prevent it, but at the beginning of the vessel's life; it can be done much better and cheaper then. Making big increases at parts, when a vessel gets old, is like putting new wine into old bottles.

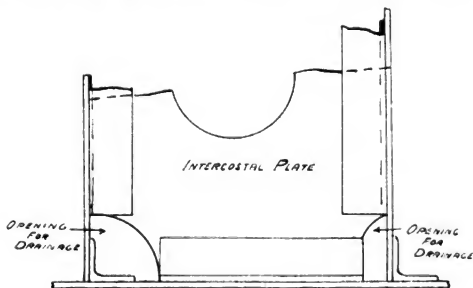


FIG. 13.

Cementing in bottoms of vessels requires close attention, for the author has noticed when examining tanks that the way the bottom cement is laid often prevents drainage along the bottom of the floors. The bottom corners of the intercostals are often blocked with cement or very little space left ; and this small space soon becomes blocked with dirt and prevents good drainage. There is no reason why intercostals should not be given a big snipe at the corners and the shell angles also cut short ; many builders fit the shell angles very close to the toe and heel of the frames and give a small snipe to the intercostal plate. The shell angle can be made sufficiently long to take the necessary number of rivets and be cut well away from the toe and heel of the frame (see Fig. 13).

All tanks should be thoroughly examined before leaving the builders' hands, as an odd rivet or bolt left lying in the tank may through time cause serious damage. The author has known cases where odd rivets were left in tanks and owing to the continual wash of water a portion of the cement was rubbed away with the rolling of the rivets, and in time the plates were rubbed through, and in one particular case this occurred in two different tanks. Tanks were reported leaking through some unknown cause, the vessel was dry-docked and the wastage found, the locally wasted parts were cut out and spigot patches fitted in way of these.

Plating under sounding pipes occasionally gives trouble owing to the necessary plate not being bedded in the cement directly under the pipe. It would be an additional precaution if doubling plates were riveted to the shell in way of sounding pipes. Several instances have come under the author's observation where sounding rods after some years (owing to no plate being bedded in the bottom cement) have made a hole through the bottom shell plating.

All sounding pipes should be carried into the tanks within a few inches of the bottom. Owing to difficulty in working into position long lengths of piping, they should at least be entered a few inches into the tank and additional short pipes be fitted to long lengths after they are in position. If the pipes stop immediately after entering the tanks and a short sounding rod be used, the rod is liable to get jammed and may be left at the bottom of a sounding pipe until the tank is opened, before it can be taken out. This remark also applies to bilge sounding pipes.

Sounding and air pipes might with advantage be much larger in diameter than usually fitted in many vessels, especially in refrigerated vessels.

The cost of painting and coating of material, if efficiently carried out, is well spent money. No comment is made here on the values of the various compositions (there is sufficient matter in this alone to form fertile ground for an interesting paper). All surfaces should be properly cleaned before coating. Parts through sheer neglect are frequently missed, such as the underside of the tank top plating, the unseen parts of frames, side stringers, &c. (See Fig. 14.) The parts marked with an arrow are frequently missed, and frames can ill afford to lose strength at this part.

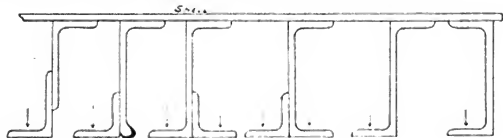


FIG. 14.

Freeboard.—In fitting scuppers to shelter deck vessels where the freeboard marking comes well up to the upper deck, it is advisable to consult the local surveyor as to what type should be fitted. In one particular instance the author knows of, the difference between fitting open scuppers and scuppers with storm valves was 10 inches (approximately) equivalent to 200 tons of cargo.

Freeing Port Area.—Where this is necessary in connection with freeboard, care should be taken to ensure that the minimum freeing port area is fitted or exceeded; if the minimum be not fitted it will lower the freeboard marking considerably, thereby lowering carrying capacity.

Bilge Keels.—The ends of bilge keels should be rounded and fitted close to the shell, for often a bilge keel catches some obstruction and is torn off. Ill-fitting ends of bilge keels are a continuous source of trouble in catching and jamming wires and ropes.

Downton and Hand Pumps.—Such pumps are useful pumps, yet the author often wonders if they should really be fitted to vessels, for only in one out of four vessels (and this is a modest estimate) are these pumps kept in a workable condition, the pumps in the other three being overhauled, made workable and examined under working conditions at the special surveys only. They are then unattended and untried for four more years.

Watertight Doors.—There is room for improvement in the general type of door used in the ordinary cargo vessels; if in an emergency,

a ship's life depended on some of the doors, it would be rather serious. Too much time is taken in closing many of the present-day doors. It might be an addition to safety if there was a regulation stating that a door of a given size should close in a stated time.

Double-bottom Tanks.—Some advantages could be obtained if the centre girder of midship double-bottom tanks in all cargo vessels were made watertight, so that the tanks would act as trimming tanks.

Particulars should be placed on board every vessel so that the master would know what his vessel could stand up to. The author has known of cases where vessels of box form entered a dry dock in light condition, double-bottom tanks full, no coal in upper bunkers, these with all double-bottom tanks empty would have been quite stable. In dry dock, tanks were emptied for examination, and when ready to float the masters insisted that all double-bottom tanks should be filled, and that the vessels should undock in the same condition as they entered. At these docks the only way of filling tanks was by a 2-inch hose, so it can be imagined what time was lost, and this when dry docks were unobtainable.

Accommodation.—Arrangements should be made in fitting wood-work in accommodation in way of sidelights, so that it can be easily removed to admit of coating and examination at surveys. If not so arranged the removal of it is costly, and wastage sets in rapidly in spaces where sidelights are fitted.

All openings in plating should be fitted with round corners; no matter how small a radius, the larger radius the better, as they are not so liable to fracture as square corners.

Air pipes and scuppers should be kept clear of spaces next bulkheads, so that caulking of bulkhead bars can be done if necessary.

The shell angles of double-bottom tank intercostals should always face the centre girder owing to rise of floor; fitting them this way ensures better workmanship.

The joggling of frames should not be done in way of the forward and after peaks owing to extreme open bevels and formation of frames, the joggle would partly disappear in the bending of the frame when hot.

The rudder trunk should be of sufficient size to enable easy shipment of rudder.

Frames if carried round bilge, owing to difficulty in furnacing, should not exceed 11 inches if bulb angle and 9 inches if channel.

Gangways should be arranged so that they are free of all scuppers and discharges.

REPAIR WORK.

This is important and usually costly work, and excepting damage causes, few repairs should be required in vessels for many years, provided construction is efficient. Many vessels are frequently neglected in their early years, and once wastage sets in it is difficult to arrest.

Much space cannot be given in this paper to repairs, yet there are a few items which should be mentioned.

It is often considered necessary in repair work that anything dealt with should be put back in the same way as before it was dealt with; the owner is duly entitled to have it so, but should he desire, cropping and part renewing or compensating in other ways may be arranged, although in every case where alterations or equivalent methods are proposed, the surveyor should be consulted to ensure that new arrangements be made equal to requirements.

The method of patching up work with doublings is often unsatisfactory; doubling is unavoidable sometimes, but when and where it can be avoided it ought to be.

Thickness of plates often receives too little attention, and much material is wasted in repairing; in some districts 20ths and 50ths of an inch are unknown. The known thicknesses are $\frac{1}{4}$ -inch, $\frac{3}{8}$ -inch, $\frac{1}{2}$ -inch and $\frac{5}{8}$ -inch. Much heavier plates than necessary are often fitted in repairs due to wear and tear, and these may have the effect of making the new part too stiff, and the surrounding area weak in comparison.

The burning out of rivets in repair work is now almost universally adopted, and in this practice, caution must be exercised to ensure that the plate or sections are not damaged by the burner in way of the rivet holes. If material has not to be replaced it does not matter, but if intended for replacing seriously damaged rivet holes from this cause may necessitate renewal. Before replacing plates recountersinking of rivet holes is necessary with a slightly deeper countersink than formerly, so as to remove any effect left by burning out.

A practice sometimes carried out is burning holes in plates and sections already in position, this leaves a very irregular formed hole with slag globules attached to the side of the hole furthest from the burner, the holes are not dressed and the rivets are put in and hammered up; this practice should not be permitted as only bad results and inefficient work can follow. If holes are blown through material by burners, a size smaller than necessary should be made and

then rimmed out to the necessary size. The author regrets to say that he has occasionally come across the first method, and has also seen unfair holes being burned fair; this is bad practice and cannot be accepted.

The value of light plates owing to wastage decreases quicker than heavy ones.

Welding is a subject of which much might be written, but to sum it up, it can be put down in repair work as a very unknown quantity, owing to the lack of means of proving its efficiency on the spot; so much depends on the workmen that it is only reasonable that certain welding should be kept under observation and examined periodically before it can be permanently accepted.

The different parts of a vessel where one may expect to find wastage or requiring attention are usually as follows, viz. :—

(1) Rivets in fore keel and after keel. In a bar keel, the flange of garboard strakes.

(2) Shell plating where cables rub and in way of bunkers and sidelights.

(3) Overlaps of bilge shell plates.

(4) Rivets in rudder.

(5) Rudder pintles and gudgeons.

(6) Rudder head in way of deck gland.

(7) Plating of bottom shell (if vessel on certain trade routes).

(8) The shell plates in fore body and after body in way of heels of frames, owing to the vessel almost continually trimming by her stern and causing any moisture to run down the heel of frame.

(9) Studs of chain cables and link ends.

(10) Aft peak and fore peak wash bulkheads, and top and bottom connections.

(11) Riveting of deep floors above stern tube.

(12) Peak frames and reverse frames.

(13) Double-bottom tanks under engines and boilers, ends of adjoining tanks to engine and boiler space.

(14) All tank end floors at top and bottom edges of frame and reverse frame angles.

(15) Rivets in panting arrangements.

(16) Margin plates and wing brackets in engine and boiler space.

(17) All bunkers.

(18) Wing plates of all watertight bulkheads, along base of bulkheads in way of ceiling, and in way of stokehold flooring.

(19) Decks immediately under coaling hatches.

(20) Frames immediately above 'tween deck cement pockets and bilge spirketing.

(21) Fidley top plating around funnel.

(22) Weather decks.

(23) Erections in way of steam pipes.

(24) Hatch fore and afters, shoes and covers.

(25) Vent coamings and cowls.

(26) Rust drawn rivets in casings and deckhouses.

In damage cases, each one must be dealt with on its own merits.

Much more might be written on many items in connection with repairs and there is ample scope for a future paper dealing entirely with this subject.

The Paper was accompanied by plans which have been reproduced in the text.



DISCUSSION.

The Chairman The CHAIRMAN remarked that the author had embodied in the paper such an amount of material and expressed definite views on such a large number of points of the very greatest practical value and interest to those connected with the shipbuilding and ship repairing industry, that there would, no doubt, be a most interesting discussion. Before that discussion was commenced he would ask them to signify in the usual manner that they heartily accepted and approved of the paper and accorded their cordial thanks to the author.

Mr. Willett Bruce Mr. W. J. WILLETT BRUCE was of the opinion that the author's contribution was the production of a very great experience gained from practical observation.

The author, in dealing with the general work of shipbuilding, had certainly touched upon most important points which were, to the ship-builder in particular, perhaps not as deeply felt at the time of the actual construction of the ship as to those people who eventually had to run the ship and found instances of such developments as the author described in certain portions of his paper. He would not pass much criticism as he felt there was very little room for it; however, there were many present who, he was sure, would give them the benefit of their experience coupled with their opinions in regard to the various points in detail.

Referring to page 259, in which the author alluded to the old time-honoured fitting of Downton and hand pumps, the fact of these being fitted in steamers and examined periodically on an average once every twelve months, then put away and never used again, had been before him and in his mind for many years. He had never seen the practical use of these being fitted in the ships. During his many years of experience he had no record of hand bilge pumps having served the purpose intended, in cases of emergency. During the war, if they had had to rely upon hand bilge pumps, particularly in vessels of large tonnage that were stranded, either to free water or to keep it from rising, they would have been badly left and disappointed. In view of this he thought that they were superfluous in ships of the present day.

The question of watertight doors arose and was most important,

and he agreed with the author that certain types of doors which were fitted to ships might be very materially improved upon regarding the time which they took to close. He thought that this point had received considerable attention since the Convention, and the doors that were at present fitted were a vast improvement in that respect and the time in closing had been much reduced, but there was still scope for further betterment.

Mr. Willett
Bruce

Referring to the question of double bottom tanks, he agreed with the author that the ship's people should be furnished with full details as regards the stability of their ships. He was afraid that in many instances, the interested departments worked somewhat by rule of thumb. In the instance of any steamers going into graving dock—possibly in some cases with a great deal of cargo on board—when the time came to take them out, no matter how careful the people on board were in making their calculations, there were instances when information was put aside in favour of the practical experience they had had on past occasions. He thought, therefore, that while it was well to provide the necessary information, regarding the stability, for those who were working her, he would not always like to see the theoretical stability data relied upon in such cases, where it was definitely known that certain conditions had changed but only an assumption of those changes could be arrived at.

Mr. B. G. OXFORD, speaking on the question of intercostals, was afraid that by leaving out one in fifteen there was a risk of uneven spacing in the floors. He considered the spacing of rivets shown in Fig. 1 very objectionable, as in course of time the frames would be rust burst. The difficulty could be got over, and was sometimes done, by omitting one of the landing rivets. In regard to joggling and flanging during frosty weather, he had known a number of failures due to this cause and had taken re-tests of the material, but had never found it defective in quality.

Mr. Oxford

He did not like the masts and spars shown in the paper. No doubt they would be easy and cheap to make, but the sharp corners were a source of weakness and the masts and spars would be much larger and heavier than round ones of the same strength. He did not see much objection to double flanging of tank margin plates over a large part of the midship portion of the vessel, and considered that every rivet that could be dispensed with was a decided advantage.

With regard to leaving loose bolts and rivets in the bottom, he did not remember any case of serious damage in a tank, but had found the shell plating cut through in places with open floors. He doubted

Mr. Oxford whether any type of watertight door could be described as really satisfactory.

Mr. Rettie Mr. CHARLES RETTIE remarked that there were several points in the paper which interested him as an electrical engineer. On page 252, the author referred to the different methods of heating rivets, but had left out one system and that was the electric heating, which was now used in the United States. It was very unpleasant at times on the ships when the riveters' fires were going, the fumes and smoke being so great that it was impossible to carry on any work. He was sure if electric heaters were used, the extra cost of running would be more than compensated by the time saved by the riveters themselves and other tradesmen working in the vicinity. He had known the riveters to have their fires a long way from their work for the same reason, whereas if they had electric heaters they could have been used right on the spot where they were working.

Referring to the Downton and hand pumps, great improvements had been made in recent years. On one ship on which he had been, three-phase electric pumps were used to advantage, as they could be run under water. Rotary converters had to be used to change the current from continuous to alternating current, the reason being that on a three-phase squirrel cage motor there was no wire wound on the rotor, consequently there was little or no insulation to go wrong, the fact that it had been known for an alternating current motor to work under water for two years spoke for itself. A good deal of research work could be carried out in connection with watertight doors, particularly regarding the electric appliances, to ensure that they would work at the proper time. He recently had to do with the installing of an electric tell-tale system connected with watertight doors which seemed perfect, but he thought a good deal might be done in improving the systems, by introducing more perfect methods to ensure that the systems already in use would work at the critical moment. It was interesting to note that in a leader which appeared in the "Electrical Review" during the war, that this country was six months behind any other country in the use of electrical appliances on board ship. When the war broke out, things which they thought were childish were now being developed, and simple though useful electric appliances were being used for many purposes on board ship, both where the ship was under construction and after the ship was finished. He would like to ask the author's opinion on the question of making fixtures in the construction of ships, such as the fastening up of electric apparatus. It had been reported that the difference in cost of

the drilling on two sister ships, built in separate yards, was £400. It turned out on investigation, that it was the rule in one yard wherever possible to use bolts instead of drilling and tapping; in the other yard they always tapped and drilled. It would be interesting to know where Lloyd's came in, as it was essential that all electrical apparatus on board ship should be securely fixed, and bolting appeared to him not to be as secure as drilling and tapping the holes. Mr. Rettie

Mr. J. DYKES wished to confirm what the Chairman had said about the author's very able paper, drawn from his vast experience both at home and abroad. It was not for him to congratulate his colleague, it would be like painting the lily. The paper fitted in with his own experience, it was a practical paper and should be much appreciated owing to the large amount of real information it contained. Mr. Dykes

With reference to the masts, he thought that it was a good idea and it was a good design, very handy, cheap and efficient, and well worth trying. All the costly work usually in masts would be dispensed with, and in addition the mast could be repaired in place if found necessary.

About the cementing and drainage of ships' bottoms, he had seen several vessels which had been built by leading shipbuilders having only a coating of cement in their bottoms, and not with about two inches or more in thickness as was usual, and on examination found that this coating preserved the skin of the bottom equally as well as putting it on two or three inches in thickness. The thin coating of cement allowed a free drainage throughout the whole ship, there was practically no lodgment of water, and this enabled more cargo to be carried than with the ordinary method.

Dealing with the matter of Downton hand pumps, he had found a portable hand pump very handy, it could be got down to clear the bilges when the ordinary bilge pumps were choked with ashes at the strums or rose boxes, which were sometimes placed where they could not be got at to clear them, and this was a serious thing, especially in the Atlantic, with a tramp steamer shipping seas over the fiddley and choking the strum boxes with ashes, &c., which he had experienced on several occasions. He thought it ought to be made compulsory to have a portable hand pump on board every seagoing vessel, just the same as they were compelled to have wireless.

As to the accommodation in way of the ship's side, it was a very expensive thing for owners at a survey if the wood lining was not arranged in such a way that it could be temporarily removed if necessary. It was far better to have no close ceiling fitted, as it

Mr. Dykes allowed rust and scale to accumulate behind the boards and serious wasting went on. Without it one could always see the side plating and preserve it from corrosion. Most of the Atlantic liners did not fit close ceiling in the berths, as it was unnecessary.

Mr. Fyfe Mr. C. F. A. FYFE thought that it was very important that there should be efficient drainage holes through the bottom floors of the tank, as stated on page 246. On page 256 the author referred to "The Putty Pump." He took it that was used for tanks carrying water rather than for tanks carrying oil.

Eng.-Capt. Ward Engineer-Capt. J. T. H. WARD took it that the author was in agreement with what he stated on page 241, that "the plates on port side of vessel are countersunk from the side the holes are punched from, and the starboard plates from the opposite side or vice versa," yet further on the author laid very great stress on the plates being a close fit in order that there should be no collar formed on the rivets. Now it seemed to him that it would be much more desirable that all the plates should be punched from the inside—that was, the face of the plate which bore on the adjoining plate—as the hole made by the punch was slightly tapered, being smaller on the side that it was punched from, besides which the rag on the plate would be on the side opposite to that side from which the plate was punched, and if this happened to be the facing side, the rag would tend to keep the two plates apart.

With reference to the rivets being nobbled over, it was all very well to say it was not right, which was generally admitted, but how was it going to be avoided? The workman of the present day, speaking generally, appeared to be quite indifferent, so long as he got through the job, for he appeared to have no pride in his work and took no real interest in the efficiency of his workmanship. It was all very well to say it was well worth looking into, but it meant at the present time close supervision whilst every rivet was in process of being hardened up.

It was a very interesting problem that the author had put forward regarding the design for masts and derricks, and he thought that it was well worth trying, as the design would give an equal strength to the existing design, with possibly but slight addition in weight, if any, and less cost of construction, besides which a repair could be effected much more easily, although the repair of steel masts and derricks was fortunately not of very frequent occurrence, and it seemed strange there was no record of this design having been tried before.

Mr. Wood Mr. W. WOOD observed that it was just about 25 years since he

entered a shipyard and commenced to study plating methods, and the inevitable question seemed to be "what changes and improvements, if any, strike one most in considering the practice then and now." Dealing first with the preparation of material, there was no doubt that the most striking change and advance in methods was the extended use of loft templates. Information for preparing almost all parts of the ship's structure was now furnished from the loft, and by an intelligent application of the principles of geometry the number of these battens was reduced to a minimum. One advantage of template methods was that the preparation of material could go forward without regard to the weather, an important factor in this country. Formerly on wet days the whole yard was closed down and the men were sent home! Nowadays the few men erecting and assembling were withdrawn to indoor work, and very little time was lost. This must result in a gain in output. He might be mistaken, there were other causes operating, but he could not but associate this with a marked change in the habits of the men. Twenty-five years ago, when a plating squad contracted for a piece of work they received about £1 each and adjourned to the nearest public-house, where they remained until the money was gone. This sort of thing occurred at regular intervals, while the work was in hand, with frequent absences and bad work due to clouded minds. At the present time he had 105 platers under his supervision and none of these men had lost time, or were likely to lose time, through over indulgence in alcoholic drink. He was inclined to think that the intervals of compulsory idleness were largely responsible for the intemperate habits of some of the black squad. Generally speaking, as one responsible for cost, quality and output of plating work, his experience of template methods had been very encouraging.

Mr. Wood

Turning to the mechanical side of ship production, the greatest change in methods was due to the introduction of the automatic multiple punch. Years ago the American shipyards, notably on the Lakes, developed template methods to the limit, but it was popularly asserted that the resultant plating had to be sewn, as it was impossible to get rivets in the holes, this being due to unfair punching and mis-applied templates, an undoubted drawback to these methods. The multiple punch did much to remove this objection. Being operated by readily adjustable gearing, a mechanically perfect pitch was obtained, which could be varied as necessary and the standardization and simplification necessary to afford the best economic results, reduced the possibility of error, due to the incorrect application of

Mr. Wood many varied pitch battens. He had the pleasure of showing the author over a multiple punched deck of a 450-foot cargo boat, and he thought that the author would agree that it was as nearly perfect as it needed to be. The multiple punching of that deck gave them a perfectly regular standardized pitch transversely and longitudinally, forming an absolutely reliable foundation for all bulkheads, girders, hatches, casings, &c., connected with it. Comparing the actual punching with hand punching the contrast was no more and no less than the difference between science and brute force.

On page 239 the author suggested that template methods had not lessened the time for construction.

It must be remembered that the marking of material was only a part of the process it underwent, and unless the succeeding stages of machining, assembling, fairing, riveting, &c., could also be speeded up, the gain in templating would not be so obvious. During the war period, by giving special study to every stage of the process, the period required to build light cruisers was reduced in Cammell Laird's from two years to 10 to 12 months. He thought all who were associated with that work would agree that these results would not have been possible without the fullest use of template methods.

The author suggested, on page 240, that a slight error in placing amidships would compound itself at the ends. While every care must be taken at each stage, especially in hornings, it would be found in practice that a system of loose plating was fairly elastic, and with giving and taking a little in the holes a lot could be done to reconcile it with the remaining structure. It was much more important not to rivet isolated portions before this adjustment was made. Again, the author stated that bars of 50 feet length did not stretch in punching. That was not his experience. It depended upon the thickness and the pitch of holes, and he preferred to drill important structural bars over $\frac{1}{2}$ -inch thick and 40 feet in length. Where bars were punched in the automatic machine, obviously one flange would be perfect, as with one end held by the feed the stretch must go to the trailing unpunched end. The punching of the second flange would throw out the first one somewhat.

On page 240, the statement was made that an allowance of $\frac{1}{8}$ -th inch in 8 feet should be made for round of beam, in preparing templates for deck plating, as the plating travelled round a greater radius than the beam. He considered this statement misleading. Theoretically some allowance should be made, as also for the joggling of edges where this was done, but speaking from an intimate daily experience,

he could say that no such allowance was made nor was it necessary. Mr. Wood
What the author had in mind, he believed, was the allowance necessary to bring the holes fair when the beams were punched straight and afterwards cambered. Under these circumstances a varying allowance must be made proportionate to the position of the neutral axis of the beam and the amount of camber, and where it was intended that the pitch in the plates should be the rule spacing, the beam pitch batten must be shortened. The statement was made that in multiple punching shell plating, it was customary to punch all the plates from one side, and that consequently all the plates on one side of the ship were countersunk from the smooth side, and on the other from the rag side. That was not the practice in Cammell Laird's. As was well known, shell plating was generally worked in alternate raised and sunken strakes. The sunken strakes were punched from the outside. This gave all the landings and one butt right, and the frames and after butt punched from the wrong side. The outer or raised strakes were punched from the inside, and in this case all the holes were punched correctly with the exception of the forward butt. In important parts of the structure it would often be found that the butt riveting was $\frac{1}{8}$ -th inch more in diameter than the frame riveting. This being punched frame size and rimmed out at the countersunk table gave a very satisfactory result.

Reference was made, on page 242, to the grouping of frame rivets to suit multiple work, and this was illustrated in Fig. 1. One speaker had criticised this arrangement on account of possible corrosion, due to imperfect closing of the parts. He might rest assured that it had been fully considered by the Classification Societies with a due regard for structural strength and efficiency. Accepting Lloyd's requirements as a standard, the pitch of frame riveting generally was 7 diameters, and treble riveted lap butts $3\frac{1}{2}$ diameters. This gave an ideal multiple arrangement, as the punches were then adjusted at the $3\frac{1}{2}$ pitch, intermediate punches thrown out of operation at the frames. In a heavier class of vessel where the frame spacing exceeded 26 inches, or the depth of frame girder exceeded 11 inches, the frame rivet pitch must be reduced to 6 diameters. It was obvious that the closer pitch was not to resist corrosion, but to afford greater structural efficiency, and this end was achieved by grouping the rivets to give a number equal to that required. Lloyd's quadruple butt spacing was 4 diameters, and where these butts were general the frame rivets were grouped at 8 and 4 diameters. The 8 diameter pitch was never exceeded, and as it was the usual Admiralty pitch for frame rivets, he did not think

Mr. Wood it should be considered unduly wide. It would be found that the British Corporation and Bureau Veritas Rules differed from Lloyd's, but the same method was adopted, and both Societies had accepted the principle.

One point might be noted before they left the frame riveting. The sketch showed the narrower pitch, apparently $3\frac{1}{2}$ or 4 diameters next to the landing. When this arrangement was first considered, Lloyd's asked for the rivet to be arranged in this manner, but as it came too near the joggle on outside strakes, and showed the neck of the rivet, he suggested that they should give them their rule spacing there, and this was done. Lloyd's quintuple overlaps were specified at $4\frac{1}{2}$ diameter pitch. Something similar would be found in the British Corporation Rules. It would be obvious that if complete rows at 4 diameters were punched, unnecessary extra rivets would have to be paid for. To avoid this, selected rivets should be omitted in the inner rows, so that the required number only were punched.

On page 244, the author appeared to question the utility of the multiple punch as applied to varying designs of docks and vessels, and also its economic advantage to the employer. On the latter point he would prefer not to quote comparative figures, which might in another place, and under different conditions, be used against him, but as one responsible for plating costs and output he would consider it a great mistake to discontinue its use. Regarding its application to varying designs, it was important to remember that all those were areas divided into plates, and that these plates were united by an arrangement of rivets, in most cases determined by a classification standard. In 12 vessels, recently built by Cammell Laird's, the pitch of beam riveting had been 7 diameters and edges of deck plating $4\frac{1}{2}$ diameters divided into the frame spacing. The result had been that hundreds of plates could have been transposed from one ship to another. The design had varied widely but the plates had had standardized riveting, this being the maximum rule pitch. In mercantile work, shell, keel, tank top, decks, bulkheads, oil fuel tanks, coal bunkers, and shaft tunnel, had all been successfully dealt with by the multiple punch. In the super-dreadnought "Howe," partially constructed, the double keel, vertical keels, outer and inner bottoms and longitudinals, were all punched in the multiple with excellent results. He considered that this established the utility of the multiple punch. He hoped that he had not dwelt unduly long on that subject, but it was one upon which there existed a good deal of misunderstanding and worth a paper in itself.

With the remainder of the author's remarks he found himself generally in agreement, but with regard to the bevelling of beams he had only arranged for this to be done in very exceptional circumstances. As a rule it would be found that after the beam left the knee it would over normal to the sheer. Mr. Wood

Regarding the square masts, he had seen a number of the new American vessels with them, though probably differing in detail from the author's design.

The AUTHOR, in reply, said that Mr. Willett Bruce had spoken on the subject of double-bottom tanks and the docking of vessels. He agreed with Mr. Willett Bruce that with many passenger liners and vessels of fine form there was a difficulty in making hard and fast rules to be given to the masters, but with vessels of full form and comparatively flat bottom he did not see any difficulty at all in arranging some particulars for masters to go by, when the vessels were in light condition. Nearly all vessels were dry-docked when in this condition. The Author

Mr. Oxford had referred to the grouping of holes as shown in Fig. 1, he was also of the opinion that this method would cause corrosion to set in more quickly; this was one of the difficulties in the arranging of multiple punched work, but it could be got over by using the second method described on page 242—that of adopting the frame hole spacing and putting intermediate holes in each row in the overlaps.

With reference to the masts and derricks, personally he could not see any reason why they should not be fitted on ships. The usual lifts for masts and derricks varied from three to five tons, and if anything heavier was lifted, additional staying was fitted (or derricks carried specially for heavy lifts) and it would be quite a simple matter to fit extra stays to this section. Perhaps he should state that the flanges of the mast section would look fore and aft and thwartship. It was difficult to get people to throw aside old time prejudices with regard to a new design, masts were no exception, and the round section handed down from the early ages would probably have life-long support from many.

Regarding the flanging of the bottom of tank margin plates to form the shell connection, this had been tried by a number of well-known shipbuilding firms and had been eventually dropped, owing to the finished cost of these being more than that of fitting an angle bar. Margin plates required a shell connection of three and a half or four inches, and it was very difficult accurately to fit such a flange with a small radius on a plate of margin thickness when cold, owing to the

The Author different radius at either end of flange and to the constant change of form along the flange, which in very few plates was straight. The flange of the margin plate which formed the connection to the tank top plating usually had a considerable open bevel, was about ten or more inches in width, was straight, lent itself perfectly to flanging and was adopted by all builders.

Mr. Rettie had made some remarks on electrical equipment. Personally he could give no actual details of the stated advantages of electrical rivet heating. Heating rivets by electricity had been tried by many firms in the United States and Canada, and he understood that it had not been successful enough to take the place of coal or coke, as nearly all American yards used the latter. The British riveter preferred the old way, and instead of supplying the necessary air force from hand or foot driven bellows, several firms had introduced the leading of a half-inch flexible hose with a $\frac{3}{8}$ -inch nozzle to the rivet heater from the yard plant. This method of rivet heating was efficient and it would be no advantage to adopt a method of which they had no actual experience. Regarding the question of bolting and tapping, he did not think this applied very largely to ship construction. As to electrical pumps, there might be an advantage in their adoption but the pumps he referred to were worthless on board a ship.

The suggestion made by Mr. Dykes that a portable hand pump should be carried, was a very excellent one, and he thought that every seagoing vessel should have such a pump as part of her equipment. Mr. Fyfe had spoken of the use of the "Putty Pump" in watertight and oiltight work. He stated that this pump was occasionally used in oiltight work, but not so frequently as in watertight work, owing to the riveting being more closely spaced and to more care and better workmanship being given during construction.

Captain Ward had referred to the punching of the holes and the statement that if they were so punched the plates could not fit close. He thought that was qualified in the paper where he had referred to the punches and dies. In addition, the holes so punched were given a deeper countersink.

Mr. Wood had stated that he had seen masts of a similar section to that shown in Fig. 5, fitted on some of the new American vessels. Personally he had never seen or heard of any such masts being fitted on any vessel of any nationality, and so far as he knew, no mast of this section had ever been built. Square sections had been built and used as derrick posts, hold pillars, &c., but were of such a design that all riveting operations could not be done entirely from the outside.

With reference to the question of punching bars of long length, the particulars given in the paper were based on the working of one particular Clyde shipyard, where bars up to 50 feet lengths, such as centre girder and deck stringer angles, were punched by the automatic punch and did not stretch in the punching. All bars in this yard, irrespective of length and thickness, which came in way of multiple punched plating work, were punched by the automatic punch. Referring to particulars of stretch allowance on beams where deck beams and deck plates were marked from battens, it was necessary to give such an allowance, as the holes in the beam were punched previous to it being cambered. It was not possible to punch a beam after cambering at the automatic punch, as the table along which the beam passed was flat.

No stretch allowance was given to hole spacing in plates and sections on account of joggling. When the grouping of holes was adopted in conjunction with the joggling of framing or shell plating, the frame holes of the outside strakes of plating nearest the joggle frequently came in way of the joggle and were unsatisfactory. This was got over by adopting the second method as described on page 242 and mentioned when dealing with Mr. Oxford's remarks.

The bevelling of beams in vessels with considerable sheer was done in many shipyards and ought to be. To explain it more clearly, he might take as an example, an ordinary cargo vessel of moderate dimensions, with one or two tiers of panting beams in the forward hold abaft the collision bulkhead and in line with the side stringer. Owing to a wide stringer plate only being fitted on the beams, the necessity of bevelling was shown. If these beams were not bevelled and the line of side stringers rose considerably as it went forward, the stringer plate would show a flatness on the beam and a fore and aft camber between every two beams, or be as shown on Fig. 4, until the collision bulkhead was reached. It was not reasonable to expect a large sized deck beam, or even a small sized beam (as the deck plating thicknesses were in ratio to size of beams) being as they were securely fixed by beam knees or web plates at the ends and by deck girders or pillar at centre or quarter distances, to wind themselves to the true line of deck plating having a considerable sheer.

He thought that he had dealt with all the points raised and thanked those who had taken part in the discussion and all present for the cordial reception which they had given to the paper.

30th March, 1921.

J. R. DAVIDSON, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E.,
President, in the Chair.

The Council reported that the following elections had been made :—
DONALD BURNS GEBBIE and ANDREW PITKETHLEY, as *Members*; WILLIAM
LEONARD OWEN and ARTHUR COLLINGWOOD WYNNE, as *Students*.

“Considerations on the Choice of Materials for Pressure Aqueducts.”

By F. W. MACAULAY, M. Inst. C.E.

THE Great War, now happily receding into the depths of past history, has left behind it what—to adopt a medical term—may be called “sequelæ” to trouble the body politic. Many of these, like their physiological equivalents, may, if not very carefully watched and dealt with, prove more weakening and disastrous to the body, enfeebled by the original disease, than was the latter itself, but, on the other hand, if they are wisely and well tackled, then the patient may be actually better and stronger, more healthy all round than he was before the disease attacked him.

One of these sequelæ is the condition of general relative poverty in which this country now finds itself and is likely to remain for many years. From this condition the engineering profession is suffering certainly no less than, probably even more than, most others.

The money so absolutely necessary for the carrying out of large engineering projects is very far to seek, is not, indeed, at the moment, forthcoming. The most rigid economy is, of necessity, being enjoined upon and to a very great extent being practised by, the many public bodies upon whose initiative depends the prosecution of large engineering undertakings. Many are not even putting in hand works which are really needed. It cannot, however, be urged too strongly that true economy does not consist merely in not spending energy or money, indeed that this is very often the actual reverse of economy.

Economy, rather, consists in spending energy or money, but in spending it wisely and to the best advantage.

When the immediate panic condition—under which public authorities who embark even upon absolutely necessary expenditure are liable to be labelled as “wasters”—has passed, the era of true economy must set in. It must be an era in which the engineering profession is bound to benefit enormously in a direction which should be welcomed by all. Engineers will be driven, more nearly than they were in the past, just before the war, towards the ideals of their profession. Hitherto labour and materials have been cheap, they will no longer be so. “Rule of thumb” and “fashion” will no longer obtain, and all will be obliged more closely and carefully to study means and ends, to attain the latter by the most scientific and economical adaptation of the former that can be devised. The text that was given to the author when, nearly 40 years ago, he first entered an eminent engineer’s office, “Don’t cut things fine! If your work “stands you may not get any kudos, if it doesn’t, you are sure to get “plenty of kicks!” will no longer hold good. Engineers will have to cut things fine—not too fine, of course—and risk an occasional kick—and be all the better engineers for so doing.

Amongst the many questions which engineers have thus to solve, as economically as possible in relation to existing conditions, is one which is of vital importance to all who have to increase, or even to maintain, the supply of water to towns large and small. It is that of the material of which the necessary mains shall be constructed.

Without diving back into the Dark Ages, when pipes of wood or stone were used, or dealing with conduits not intended to convey water under pressure, it may be stated that up to very recent years practically the only metal used for water mains has been iron, either in the form of cast-iron or steel, in the shape of tubes protected as a rule against corrosion by internal and external bituminous coating.

It would appear that cast-iron pipes, as originally made, were entirely satisfactory. The author has heard of—though to his regret he has never seen—cast-iron pipes which were taken out of the ground after a continuous service approaching 100 years, and were found to be as sound and free from any corrosion as they were on the day that they were laid, and—wonderful to relate—they were not originally dipped in or painted with any protective coating. The author believes that they were used for the conveyance of a hard deep-well water only and this, coupled with some quality in the old cold-blast iron of which they were made, may account for their preservation. As against this, some 30 years ago some similar pipes, then said to be about 70 years old, were taken out at Middlesbrough, when it was

found that whilst the interior and exterior skins were perfect the interior metal had perished, having become quite soft and spongy. These pipes cannot have been under any pressure, they were used for the conveyance of water pumped from the river Tees a few miles above Middlesbrough and filtered through slow sand filters. Such water would undoubtedly "go for" modern cast-iron pipes, so—as before—some rust-resisting quality in the metal may be argued, but it is difficult to account for the condition of the body of the pipes.

However this may be, there is no doubt that water engineers who have the charge of cast-iron mains laid within the last 30 or 40 years, especially those—a growing number—whose supplies are drawn directly from upland gathering grounds, are to-day faced with very serious difficulties and problems owing to the more or less rapid deterioration of the discharging capacity of their mains. As an instance, it has been found that the three cast-iron mains on Manchester's Thirlmere aqueduct lost 35 per cent. of their original capacity—calculated as quite new pipes—in fifteen years and 40 per cent. in twenty years. On the same basis, the 42-inch cast-iron and steel mains on Birmingham's Elan aqueduct lost 25 per cent. in fifteen years. The deterioration of large mains on the Leeds Waterworks is stated to be even higher, and similar experiences have been met with at Liverpool and other places.

This deterioration is caused by deposits which, forming on the interior surface of cast-iron and steel pipes, not only reduce the actual bore of the pipe but offer added frictional resistance to the flow of water through them. They take two forms, a slime or slimy streamer, and nodular or tubercular incrustation.

The first is, apparently, due entirely to bacterial action, to the presence in the water of what are now called "iron bacteria"—*crenothrix*, *cladothrix*, *leptothrix*, and others—which all thrive on iron oxides. Few upland surface waters are free from oxides of iron and few are, therefore, free from these iron bacteria. Initially, the iron bacteria depend for their existence upon the iron oxides in solution in the natural water; but it seems only natural that if they are conveyed at all into iron mains in which—by any chemical process—iron oxide is being produced, their numbers must increase enormously. The experience of Liverpool on the Vyrnwy aqueduct seemed to prove that slow sand filtration would effectively remove these bacteria from the natural water. For a time the experience of Birmingham was to the same effect, as regards, however, more rapid sand filtration; but there is no doubt whatever that now iron bacteria are present in large

numbers in the cast-iron and steel siphon mains. This, however, in the opinion of the author, is no proof that the filters have failed, that is, that they have let the bacteria through. Half of the Elan aqueduct consists of "cut and cover" and tunnel. On these lengths—as there are no doubt upon similar lengths on all aqueducts—are many places where either by design—to relieve pressure on the work—or accidentally through small cracks, there are inflows, or at least seepages, of sub-soil water. That much of this water contains iron bacteria the author has little or no doubt, for wherever the water is ferruginous and is not in quantity more than will just trickle or flow gently down the aqueduct wall, he has seen the slimy growth, so characteristic of iron bacteria, adhering to the walls above the water level of the aqueduct.

The second form of obstruction, the nodular or tubercular incrustation, takes the shape of nodules on the surface of the pipe, from a small fraction of a square inch to several square inches of base area and standing out from a small fraction to $\frac{3}{4}$ -inch or more from the surface. They are very rough in shape, apparently start as a soft body but harden with age and have the appearance of growing by accretion. Their incidence will vary, in number per square foot of surface, very much in a short length of main, ranging even in one pipe from a few odd nodules in one place to practically covering the surface in another. They can readily be detached whole from the pipe and, even the largest, may be found to be adhering to a perfectly sound area of the bituminous coating but to have their origin in an almost microscopic hole in that coating. Often the metal of the pipe about this origin will be found to have become so soft for a slight depth that it can be dug out with a penknife, nearly as often it will be apparently unaffected. The nodules contain a very large percentage of ferric oxide, magnetic oxide of iron and, at the centre of origin, sometimes a little sulphide of iron. Whether the tubercles are caused by bacterial or purely chemical action is not at present certain. What evidence there is rather points to the CO_2 in the water being the cause. Certainly the de-aeration of the water in the Kalgoorlie mains in Australia seems to have had the effect of, at least, retarding tubercular growth in them.

The author does not wish to dogmatize, even to theorize on either of these forms of deposit. As being responsible for maintaining the greatest possible flow through about 75 miles of 42-inch cast-iron and steel mains all suffering badly from the maladies of which he has just described the symptoms, he has been hunting diligently for a cure or

at least a palliative. So far his efforts have resulted in getting certain eminent bacteriologists and chemists to disagree very decidedly amongst themselves and no practicable palliative even has been proposed.

The practical consideration, therefore, is that these obstructions to flow do grow in cast-iron and steel mains and that at present there is no cure for them. Apparently no form of dipping is an absolutely sure preventive. Under the author's charge are several miles of steel main which were dipped first in Angus Smith's composition and then in a special composition somewhat rich in bitumen; to all appearances they were perfectly protected, but they are now as bad, on the whole, as regards tubercular incrustation as the cast-iron mains laid at the same time and dipped once in Angus Smith's composition.

The slime and incrustation can be removed by periodical scraping or brushing. This may not be a difficult business when the mains have been designed with that process in view, but where the economy of using sluice valves of much smaller diameter than the mains has been adopted, the brushing process becomes complicated and costly. In any case it is not satisfactory, for slime and incrustation recommence to form at once. Some authorities state that this is at an accelerated rate. The author has no personal experience in the matter, but he understands that, so far as it has gone, the Manchester experience is to the effect that the re-growth takes place very much at the same rate as the original.

As a consequence of this, in designing a cast-iron or steel main a waterworks engineer has to determine what quantity of water he wishes his mains to deliver at some future time, years hence. Then he has to guess how long it will take for their capacity to deteriorate to this minimum, decide how frequently he will submit them to the possibly somewhat destructive, certainly expensive, process of scraping or brushing, design them of a sufficiently larger capacity than is necessary for any other purpose than to meet the result of this guess and decision—and then sit down and watch the capacity of his mains fall off whilst the demand for water increases.

To turn to the actual designing of cast-iron pipes of large diameter, such as are actually being considered in this paper, that is to say, of about 40 inches diameter and upwards.

It may be presumed that the formula used might be

$$\frac{D}{d} = \sqrt{\frac{f + p}{f - p}}$$

Where D and d = the external and internal diameters respectively.

f = the ultimate tensile strength of the metal divided by a factor for safety.

p = the pressure to be withstood.

" d " is of course known, but is of necessity some inches greater than it need be, to allow for depreciation of capacity by corrosion. For " f " the engineer takes the mean of a very wide range of ascertained ultimate tensile strengths of a very uncertain metal, and because of its uncertainty allows a very wide margin of safety, dividing the ultimate strength by 5 or 6, as a rule.

Then comes " p ". He knows his hydrostatic pressure, but to this he must add a purely empirical amount to cover the shocks to which he considers the very uncertain metal may be subjected under his particular working conditions. Thus he obtains a thickness, but to that he must add another empirical amount to cover faults in manufacture—probably about $\frac{1}{4}$ -inch—at any rate in his thinner pipes. Finally, for large pipes under light pressures he may find it still desirable to add further to the thickness obtained up to this point, in order to make his pipe sufficiently stiff to avoid its being subjected to stresses set up by deformation under external earth pressure.

There are so many factors depending upon the knowledge and experience, may it respectfully be added, the idiosyncracies of each individual engineer, that omitting those who blindly take someone else's formula as fitting their own conditions—it may almost be said, "*quot homines tot formulæ.*"

In short, cast-iron pipes when they are designed, for the reasons previously given, are far from ideal, and they cannot be designed with the closeness and certainty that economy demands when the metal is costing £25 a ton—or thereabouts—in the very simplest and easiest castings!

In this respect steel is a much better metal to deal with. Its qualities are much more consistent than those of cast-iron, and it is not liable to the accidental defects in manufacture to which the latter metal is. On this account, and because of its superior toughness, a smaller factor of safety may be allowed for steel than cast-iron, whilst owing to its very high tensile strength the quantity of metal required is very much less. The empirical additions for shock are not needed, at any rate not to the same extent where probable shock is small in relation to the hydrostatic pressure. But addition to the thickness must be made to allow for corrosion and, except for very high pressures, considerable addition is necessitated in order to render the

pipe sufficiently stiff not to collapse, partially or entirely, under outside pressure, either earth or atmospheric. The author does not know of a case when such collapse has occurred in this country, but there is a well known case of the collapse of a large steel main in New York, owing to the accidental occurrence of a partial vacuum in it. For light pressures such addition might easily double, if not more than double, the thickness necessary to withstand working pressures.

Further, in practice, steel has this great advantage over cast-iron, that a pipe made of it is not liable to fail under pressure or shock in the sudden and extremely thorough manner in which cast-iron pipes only too frequently do.

It would appear that, of the two metals, steel possesses far superior qualities to cast-iron for pipe-making. But, as has been said, both suffer from the very serious defect that, protected by the best of bituminous coatings, they are subject to serious internal deposit and corrosion which causes very considerable loss of capacity in a comparatively short period of their life, whilst the corrosion tends materially to shorten that life.

The problem, therefore, would appear to be to find a method whereby the theoretical quantity of steel, necessary to withstand internal working pressures, may be formed economically into a pipe in which the metal will be protected absolutely against corrosion and bacterial action, and at the same time be rendered sufficiently stiff and rigid to resist deformation by external pressure.

The solution of the problem, the author believes, is to be found in some form of reinforced concrete.

Of the absolute protection from all corrosive action which is afforded to steel by a thin covering of cement concrete, it is unnecessary to do more than make mention, the fact is so well proved and known.

There is more doubt, perhaps, concerning the immunity from harm of concrete itself in contact with water. It may be taken as fairly sure that no ordinary fresh waters, such as are used for domestic purposes in this country, have a destructive effect upon concrete when brought into contact with it or even when saturating it, if the cement from which it is made is sound and the concrete itself well made. It is on record, however, that the water supplying Frankfort, in Germany, was found some years ago to be attacking and destroying any concrete with which it was brought into contact, and a great deal of costly experiment had to be made until a bituminous paint was found which protected the concrete. The author does not know whether in this case it was the concrete or the water which was at fault, nor is he

aware of any similar experience in this country ; but before adopting concrete pipes, a water engineer should assure himself by observation of concrete surfaces already in contact with the water, if need be by experiment, that it has no deleterious effect upon cement concrete.

Another very important consideration is, that whilst there may be some slimy deposit on the surface of the concrete, due to bacterial action, which would in the course of time increase the coefficient of frictional resistance to flowing water, nothing approaching the resistance and reduction of water area, due to the nodular incrustation on steel or iron surfaces, is known to occur on a concrete surface. In designing a concrete main therefore, the engineer has only to allow for a deterioration of discharging capacity of some 5 per cent. or 10 per cent. in the same period as he would have to allow for one of 30 per cent. or 40 per cent. or even more in an iron main. It is true that a concrete surface, as usually turned out, is much rougher than that of a bituminous-covered metal and therefore the inherent coefficient of friction of the former is higher than that of the latter ; but, as will be seen later, in some forms of concrete pipes it may be possible at probably small cost to make a concrete surface equal in this respect to a metal.

Given these most important desiderata, a material is available in which the minimum quantity of steel—the most desirable form of metal for the purpose—can be disposed to form a pipe, safely and in such a manner as to ensure water-tightness under pressure and to make it sufficiently strong to withstand external pressure. With this as the guiding principle, many forms of reinforced concrete pipes have been devised. It is not proposed to make any attempt to review these here.

Further, the author wishes very particularly to state that he holds no brief for any particular make of pipe and that, in mentioning any by name—as will be done later—it is not in any way to advertise them, they are merely picked out because he has some knowledge of them, and can consequently utilize them to illustrate points which it is desired to make.

Perhaps the best known and most widely used reinforced concrete pipes are those devised by the Frenchman, M. Bonna. These consist of a steel cylinder between internal and external steel helices of cruciform section, the whole embedded in concrete. The steel cylinder—the primary function of which is to ensure water-tightness—is butt welded and is usually thin, the range of thickness being between 2 and 6 mm. The chief element of strength is the external helix, it and the cylinder being alone taken into calculation. Variation in strength is obtained by adjustment between the pitch and cross-sectional area of the helix

and the thickness of the cylinder. The governing considerations in this are that neither of the two shall be of such dimensions as shall render them difficult to build up with temporary plant on the site of the pipe line, and that the spirals shall be close enough for the concrete to bridge over without being so close as to prevent its getting well in between them. The internal helix is very light and of fairly wide pitch, its function being solely to give cohesion to the internal concrete which protects the inner face of the cylinder. Both helices are kept in true form by being welded to light longitudinal steel bars lying along the inner and outer surfaces of the cylinder.

When the cylinder and helices are assembled the whole armature thus formed is stood on end, an external form of steel segments is built up around it and a collapsible internal steel mould is inserted. The whole is then run with liquid concrete, composed of two parts of sand—that will all pass through a $\frac{1}{8}$ -inch mesh—and one of cement. The forms are left in position until the concrete has set sufficiently to enable them to be removed without damage, usually some 12 hours. The pipe is then left to finish setting in the open. The pipes are usually 4 metres in length. The external helix with its concrete envelope is stopped a few inches short of either end of the pipe—leaving the steel cylinder exposed for that length—for the purpose of making the joint. When this process is reached, two pipes being placed end to end in the trench, about $\frac{1}{2}$ -inch apart, a light steel collar corrugated on its inner face is slipped over the opening and the annular space between it and the cylinder is caulked from either end, first with a few strands of tarred yarn, then with about 3 plies of lead piping filled with yarn. A light plain steel cylinder is then slipped over. It is about 1 inch greater in diameter than the external concrete of the pipes and overlaps the shoulder left in the latter by about 1 inch on either side. Outside it is placed a cruciform steel helix of the same length, a wooden form together with a flexible steel strip of steel sheeting then encloses the whole and is filled from the top with concrete. The space between the ends of the pipes is made up with concrete.

It may be added that the wall of a "Bonna" pipe runs from about 2 inches in thickness for smaller diameter mains up to $3\frac{1}{2}$ inches or 4 inches for mains about 60 inches in diameter.

It need hardly be said that this form of construction is not well suited for pipes of small diameter, say, less than 2 feet. Before the war it is said that the cost of a "Bonna" pipe was only about $\frac{2}{3}$ to $\frac{3}{4}$ that of a cast-iron pipe to do the same duty. It is evident, however,

from what has been said that their construction involves a great deal of more or less skilled labour, which is a serious matter in these days of very high wages.

The criticisms that may be levelled against "Bonna" pipes are:—

(1) That they are not homogeneous reinforced concrete structures but consist of three parts, the steel cylinder and the inner and outer reinforced concrete shells. That owing to the very liquid state in which the concrete has to be poured into the moulds it must shrink in setting and that, therefore, the three parts may not mutually support each other, and so may be broken down in detail under pressure. Theoretically this is quite sound, but the answer appears to be that the shrinkage is actually so infinitesimal that it is of no moment. It is stated as a fact that no "Bonna" pipe has so broken down.

(2) That in spite of the liquid state of the cement a great deal of air is imprisoned by it and, therefore, the concrete is not sound throughout, that the means adopted—namely, tapping the outer mould lightly with a hammer during running—is of little or no value in getting rid of this, and that more effective measures, such as jiggling the pipe, would add too greatly to its cost, if it could be done without displacing the steelwork. To this it may be answered that so long as the air holes do not expose or admit water to the steel members, no harm will result.

(3) That from their mode of being run, that is to say, vertically, the concrete is much denser at one end than the other, that as in a cast-iron pipe air and impurities are apt to collect in the top foot or so, but, unlike a cast-iron pipe, the top foot of a "Bonna" pipe cannot be cut off. The answer to this is similar to that to (2).

(4) That the inner surface is much rougher than that of an iron or steel pipe. There is no cure for this, unless it lies in covering the inner surface with a good bituminous paint.

(5) That the joints are exceedingly rigid and do not allow (a) for expansion and contraction, (b) for settlement. An answer to (a) would appear to have been found to some extent by the engineers of the great Pouilles Aqueduct in Southern Italy, where hundreds of miles of reinforced concrete mains have been laid. There the pipes were laid only at seasons when they could be filled at once with water at about their temperature. No movement it is said has taken place since. As to (b) the author is compelled to say that he has seen no joint yet for a reinforced concrete main which he would dare to adopt in ground liable to settlement.

(6). That in view of the amount of skilled and semi-skilled labour involved in the manufacture of "Bonna" pipes, welding and assembling the steel work, concreting, &c., and of the number of costly forms required if much progress is to be made, these pipes are bound to be costly.

"Costly" is, of course, a relative term, relative to the ends aimed at and achieved. It is impossible, therefore, to generalise on this criticism.

In recent years—during the late War, in fact—another form of reinforced concrete pipe has been very strongly brought to the notice of English Waterworks Engineers. It is the invention of an Australian, a Mr. Hume, and it is known by his name. The "Hume" pipe is made by centrifugal process. The reinforcement is in the form of steel wire. This is wound mechanically upon a collapsible mandril the diameter of which is about 1 inch greater than the internal diameter and of the length of the proposed pipe. Sufficient wire is thus wound to give the required tensile strength to the wall of the pipe. The winding is helical in both directions, with a sufficient number of straight longitudinal lengths to bind it and give it strength longitudinally. The whole wire "cage" thus formed is placed inside a longitudinally jointed steel cylinder of an inside diameter about 1 inch greater than the outside diameter of the "cage." The cylinder is the exact length of the required pipe, and has an internal flange at either end, the depth of which is of the exact thickness it is desired to give the pipe. These flanges are so shaped as to form the recess in the end of the pipe wall for the bitumen filling which forms part of the "Hume" joint. Inside the fixed flange a loose flange about $\frac{1}{4}$ -inch deep is inserted. The cylinder rests upon steel rollers by means of which it is made to revolve. This is first done at a peripheral speed of about 500 feet a minute. During this rotation sufficient fine concrete is thrown in to give the required thickness of wall. The speed is then about doubled, and maintained for 4 or 5 minutes (according to the size of the pipe), when the mould is brought to rest and the water and light detritus which has been forced out of the concrete is allowed to run off, the loose flanges being removed for this purpose. The mould is again revolved at a high speed for a few minutes, during which a screed is held against the inner surface to smooth it. After this stage the concrete is so compacted that it will not take an impression from one's thumb however hard one presses, every drop of superfluous moisture having been forced out. The mould, with the pipe in it, is then steamed for

4 or 5 hours at a temperature of 120 degrees Fahr., when the mould is removed and the pipe is exposed to the atmosphere. The concrete is gauged two parts of fine sand to one of cement.

The "Hume" joint is made by filling an inverted V shaped space, between the ends of the pipe walls, with bitumen and covering the joint with a reinforced concrete collar caulked with cement.

These pipes in small diameters, e.g., up to about 15 inches or 18 inches, have given some remarkable results under tests. In the first place, the concrete under centrifugal action gains about 10 per cent. in density over the best hand-made concrete, and it is practically non-absorbent of water. The materials, naturally, arrange themselves in the ideal manner for a water main, that is to say, that the finer particles are aggregated on the inner surface, forming a particularly dense impervious skin which is absolutely incorporated in the body of the pipe. The internal and external surfaces are very true and smooth, the latter particularly. The author, by simple means, has polished the interior surface of a short length of 12-inch "Hume" pipe until it presents a surface far better than that even of a bitumen dipped cast-iron or steel pipe. Under internal water pressure, test pipes 4 inches in diameter are said to have withstood remarkable pressures; at 250 lb. on the square inch they just showed signs of moisture in patches, at 300 lb. this became general, and at 350 lb. the water came out in a general but very minute spray. On easing off the pressure the pipe became tight again at 250 lb., and on the pressure being again increased the results at 300 and 350 lb. were the same as the first time. The process was repeated without injury to the pipe. The reinforcement in this case apparently had an ultimate strength of about 700 lb. to the square inch.

An 8-inch diameter pipe was tested up to 220 lb. by Mr. Holme Lewis with perfectly satisfactory results. A 39-inch diameter pipe carried an external load, concentrated along the top, of about 1,700 lb. per foot run without fracture.

The author has seen a 60-inch diameter "Hume" pipe 8 feet long and 3 inches thick, which seemed absolutely perfect, but it was only very lightly reinforced and was not subjected to test.

The reason for the behaviour of the pipe under the internal pressure test seems obvious. As the pressure grew the wire reinforcement became in tension. Yielding slightly to this it allowed the particles of concrete to separate slightly, thus allowing a passage for the water. As the tension increased so these interstices grew and let more water through, but upon pressure being relaxed the elasticity

of the wire closed all up again. It has been noticed that under repeated tests the results tend to improve.

Up to a point Mr. Hume evidently had not found it necessary to pay a great deal of attention to the scientific calculation of the strength of his reinforcement, he put in what he considered enough wire (mostly unravelled mining cable) for his purpose. Further, possibly for the same reason, his reinforcement did not appear to be wound at all regularly.

It would appear that, theoretically, the wire should be wound at sufficient tension just to reach its lower limit of elasticity. If this be determined at the greatest stress that will be put upon it under normal working conditions, the concrete will not then let water through. There is another reason why all the wire of the cage should be equally in tension. If it is not, under the centrifugal force developed by the spinning of the mould any strand that is looser than the others will become displaced and may (as the author has seen) appear on the outside surface of the concrete.

In considering the design of pipes of larger diameter (e.g., 5 feet) to withstand pressures above 150 lb. on the square inch, the author has found difficulty in disposing of the large quantity of steel wire required, in such a manner as to allow the concrete to get thoroughly around it and yet retain a wall that is not unreasonably thick. The patentees of the "Hume" pipe found the same difficulty and are dealing with it.

Amongst the other suggestions made is that of using steel wire of very high tensile strength—100 to 120 tons on the square inch—but there are obvious difficulties in the way of this.

The "Hume" appears to be an excellent and relatively cheap pipe for small diameters up to quite high pressures and for large diameters up to moderate pressures, but for pipes over 42 inches in diameter for pressures of over 150 lb. its value is, at present at any rate, not so obvious.

Quite early in his investigations, some three years ago, it occurred to the author—arising from the "Hume" process of manufacture—that a pipe for large diameters and high pressures could best be obtained by lining cylinders of cast-iron or steel centrifugally with a skin of concrete. The metal could thus be made just to the theoretical thickness required to withstand the normal internal working pressures. The extra thickness of metal—added empirically in designing an ordinary metal pipe to allow for corrosion and to render the pipe sufficiently stiff to prevent collapse under external

pressure—could be replaced at much less cost by a lining, applied centrifugally, of sufficient thickness to afford protection to the metal and achieve the necessary stiffness, and lightly reinforced to aid cohesion. A minimum thickness of $\frac{1}{2}$ -inch would appear desirable.

Steel sheets welded longitudinally—and possibly circumferentially for larger diameters—into tubes would be the better metal to use, ordinary cast-iron is subject to too many frailties. But there may be a great future, in this respect, for the centrifugally made cast-iron pipes of which much has been heard lately, if they can be manufactured economically. It is claimed that, by the centrifugal method of casting, a gain of tensile strength in the metal of 50 to 100 per cent. is obtained and that all the frailties referred to above are eliminated. Certainly a beautifully even homogeneous metal, ductile and approaching mild steel in texture, is produced.

The author could not induce Mr. Hume seriously to consider this type of pipe, though his patented plant is perfectly adapted for its production. A patent has recently been taken out by a South African for lining metal tubes with unreinforced concrete, and pipes from 3 inches to 4 inches in diameter up to 24 inches have already been so lined with perfect success. There appears to be no reason why tubes of very much larger diameter should not be dealt with equally well. The concrete lining appears to adhere perfectly to the metal. The external surface of the metal is naturally left exposed. Since, for economy in design, there is no thickness to spare against corrosion some form of external protection should be adopted. This can be afforded by a light—say 2-inch or 3-inch thick—cover of concrete, gauged 6 or 8 parts of fine stone and sand to one of cement, put on, *in situ*, under light movable forms, when the pipes are laid. There, however, appears to be no reason why these pipes should not be dipped as ordinary cast-iron and steel pipes are. Such dipping would not affect the internal concrete surface one way or the other, whilst it would protect the external metal surface. It is the author's experience and that, he believes, of most waterworks engineers, that in this country—except in a few localities—ordinary Angus Smith solution, properly applied, affords sufficient protection to the exterior of cast-iron and steel mains to render them practically indestructible.

These pipes are at present in the experimental stage only, but the author has estimated that they should be manufactured and laid at a cost which will compare favourably with that of plain metal pipes.

The joints of such pipes can be either socket or collar. It is a question whether the concrete lining would stand running the joint

with hot lead, but it would certainly stand stemming with lead wire or wool, whilst the author believes that the recent American practice of stemming metal pipe joints with cement has very much to recommend it.

In what he has said, the author has spoken of pipes from the point of view of the waterworks engineer, and it is somewhat curious that his investigations have led him from ordinary metal mains through reinforced concrete mains proper, back almost to his starting point, or at any rate to a combination of the two. But for sewerage and other engineering works in which cast-iron and steel pipes have hitherto been used, the author believes that reinforced concrete pipes proper can be adopted in their place with the utmost advantage.

The author apologises for having chosen a subject which may only be of real interest to a relatively small portion of his audience, but he is a waterworks engineer, and he cordially agrees with the dictum of Appelles, "*Ne sutor ultra crepidam.*"

DISCUSSION.

THE PRESIDENT remarked that the paper which had been presented that evening was of great interest to waterworks engineers. Those of the members present who were not waterworks engineers might appreciate a little homely illustration which would accentuate the importance of the subject brought forward by the author. Most of them, probably, were ratepayers, and it would therefore interest them to know what bearing the subject had in the case of the Liverpool undertaking. If the Liverpool Water Authority, to meet increasing demands, wanted to lay a new main from Vyrnwy to Prescott, and this appeared to be a very pressing need at the moment, a cast-iron main of 42-inch diameter would require, roughly, 100,000 tons of metal. When they realised that they might have to pay something in the neighbourhood of £20 a ton for the pipes delivered on the ground, and added the cost of laying the mains, it would give them some idea of the enormous cost of the work.

The President

At the present time, with borrowed money at 6 per cent., it meant that in 12 years they had to pay again the whole cost of that main in sinking fund and interest. If they took money at 5 per cent., it only wanted 14 years to run again into the cost of an entirely new main. These few figures would give them some idea of the very great importance of this subject.

They were fortunate in having at the meeting, engineers who were experts in the construction of the different types of main that had been referred to in the paper, and probably with their assistance they would arrive at something approaching the truth or as near the truth as one could arrive in these matters.

The author was the Chief Engineer of the Birmingham Corporation Waterworks and had charge of their great Elan Aqueduct, in connection with which he had had very wide experience of cast-iron and steel pipes. Evidently he was not satisfied that perfection had been reached with these metals, for he was now going in for reinforced concrete pipes of large diameter. During the reading of the paper it appeared as though the author was definitely coming down on the side of reinforced concrete, but before the end was reached he seemed to get back to a more neutral position.

The author had dealt with the subject very fairly from all points

The President of view, and they would hear the subject discussed from the point of view of those who had special experience in the particular forms of construction referred to. He would ask them to accord to the author a very hearty vote of thanks for his interesting and valuable paper.

Mr. Lancaster MR. WILFRID D. LANCASTER said that he appreciated the kind invitation of the President to be present. He would like to ask one or two questions about various points arising out of the interesting paper they had listened to and also to make a few statements, because the subject dealt with was of particular interest to him, as he had known Mr. Bonna for the last ten years. He had, moreover, been in very close touch with him on matters appertaining to the design, manufacture and laying of his pipes, and had therefore had the benefit of his admittedly extensive knowledge and experience, which he thought should carry considerable weight in the discussion, as it was the outcome of a life-long study resulting in the original, practical and successful application of his theories in the many important works carried out by him in France and Belgium in connection with steel and reinforced concrete mains for water supply and sewage pumping mains. The author sounded the keynote of economy in the opening paragraphs of his paper, but later on stated that the construction of "Bonna" pipes involved a great deal of more or less skilled labour, which was a serious matter in these days of high wages. He would like to ask the author with what particular form of pipe he was making a comparison when saying this, for he thought that it would be difficult to show that the skilled and semi-skilled labour involved was more than that involved with either cast-iron or steel pipes. He thought that the fact of "Bonna" pipes being made *in situ* tended to lead one to regard their manufacture as involving more skilled labour than would be the case if they were not thus made. As a matter of fact, he did not consider that any more skilled labour was required than in the case of other classes of pipe to fulfil the same conditions. It might appear to require more, because the whole process of manufacture was under one's direct observation when the pipes were made *in situ*, whereas in the case of other pipes which were made at a manufactory and delivered on the site ready to lay, one was apt to overlook the amount of skilled and semi-skilled labour required to produce the finished article. The author himself had answered the first three criticisms, which he said might be levelled against "Bonna" pipes. With regard to the fourth criticism concerning the roughness of the inner surface of the pipe as compared with cast-iron or steel, this he thought was

open to argument even when the pipes were new, and it would be interesting to know whether the author had been able to conduct any experiments to enable him to arrive at a coefficient of rugosity of such pipes. Experience certainly went to prove that after a few years use there was no comparison between the inner surfaces of reinforced concrete pipes and those of steel or cast-iron.

In support of this statement he quoted from an independent report made by Mr. Priestley, the Waterworks Engineer to the City of Cardiff, to his Committee as a result of visits he made in 1919, to various installations on the "Bonna" system in France, Belgium and this country.

Referring to Swansea and speaking about "Bonna" pipes that were laid in 1905, Mr. Priestley said: "Some of the pipes (24 inches diameter for a working head of 170 feet) had been inspected internally a few years ago, and with the exception of a little slime in the bottom were perfectly clean, and in as good condition as when laid."

Referring to the same main which had been opened in places for his inspection he said:—

"We were informed that in both instances the pipes had not been specially selected for inspection, but taken at random. The pipes in each case were evidently in as good condition externally as when laid—the joints were absolutely dry. These pipe lines had not had a sixpence spent on them since construction, and had been perfectly satisfactory under working conditions." With regard to the fifth criticism about the joints being exceedingly rigid and not allowing (*a*) for expansion and contraction, and (*b*) for settlement. With reference to (*a*), Mr. Bonna claimed that the joint he used did allow for the minute expansion and contraction which might take place in pipes laid in ordinary conditions in a climate like this, and in support of this claim he could point to the fact that there was no instance on record of the failure of the joint, so that the results said to have been attained in the Pouilles Aqueduct did not appear to offer any improvement on what had been accomplished by Mr. Bonna. As regarded (*b*) settlement, "Bonna" pipes had been laid extensively in the French and Belgian colliery districts, particularly in and around Lens, in bad ground, but to quote again from Mr. Priestley's report: "there had been no damage." If necessary, and where it was considered desirable, the joints could be lengthened slightly to give more elasticity to the pipe line. There were two striking instances on record of the settlement of bad ground in which "Bonna" pipes were laid

Mr. Lancaster in France. One was at Vincennes, where a main was laid over an old quarry, and owing to the subsidence of the ground a length of five pipes and joints were left suspended for several days, and though working under pressure the main did not burst or bend. A similar case happened at Nismes, in France, with the same result, the subsidence in this instance being caused by the bursting of a cast-iron main and consequent flooding of the ground in which the "Bonna" pipes were laid. When cleared up and the water pumped away, it was found that the "Bonna" pipes, 36 inches diameter, were suspended over the subsidence for a length of 60 feet, and though working under a high pressure, 250 feet working head, they had not moved or suffered any damage. This was one important factor among many others which led the Brussels Inter-Communal Water Company to adopt a single "Bonna" main for the supply of Alost, Ghent, Bruges, Ostend, Blankenberg, Termonde, St. Nicholas, &c. Had cast-iron pipes been adopted, a double main would have been absolutely essential, but the Company's 12 years' experience with "Bonna" pipes led them to decide on one single main on the "Bonna" system for the whole length of pipe line. This he ventured to think would help to dispel the author's doubts as to the existence of a joint for a reinforced concrete main which could be safely adopted in ground liable to settlement. As a matter of fact, any form of flexible joint that could be used for cast-iron or steel pipes could also be adapted to the "Bonna," as would be seen from an inspection of drawings of various types of joints adapted to "Bonna" pipes. He had with him an interesting photograph which he produced for inspection by those present, of a length of water main in "Bonna" pipes spanning the River Senne, near Brussels, at Ruysbroeck Bridge. The span was 52 feet 6 inches in one continuous length of "Bonna" pipes 27½ inches diameter on either side of the bridge. The main pipe to the bridge was 40 inches diameter, a breeches piece was formed at either end, and the pipes, of 27½ inches diameter, were carried over on each side of the bridge supported on reinforced concrete beams crossing the bridge at each end, where the straight lengths of pipe and the specials for the breeches pipe commenced.

Mr. Needham Mr. C. A. NEEDHAM was of opinion when reading the paper and hearing the author's further remarks that they were still a long way from having a perfect material for the construction of pressure aqueducts under any conditions, but as far as they had been investigated it was a distinct gain to find variations of the existing practice, which might lead them to something more suitable and

capable of giving greater satisfaction than the present cast-iron or steel pipes. Mr. Needham

The author stated, early on in his paper, that he had heard of cast-iron pipes being found to be sound and free from any corrosion after a continuous service approaching 100 years, and not originally dipped or coated. He had taken the liberty of bringing a piece of pipe which had done 50 years service in Birkenhead, was taken up and relaid. It was exactly as it was lifted and had not been cleaned in any way inside or out. The water passed through the pipe was well water and between 18 and 20 degrees of hardness. He did not think that there was anything else to account for the excellent condition in which it was found excepting that, as far as he could ascertain, the pipe was made from cold blast iron and was coated with Angus Smith's solution according to the original specification.

The "Angus Smith's solution" of to-day seemed to be anything in the nature of a black mixture which could be put on a pipe, and he was afraid that this, together with the fact that the coal tar of to-day, which was one of the principal constituents of the coating, was an entirely different thing to what it was at one time, was the reason for the greatly shortened life of cast-iron pipes of more recent times. He had for some considerable time been making notes of the composition of "Angus Smith's solution" given by various authorities, makers of pipes and others, and there was no doubt that the originator would never have recognised them as copyrights of his patented process. The original mixture consisted of 30 gallons coal tar, 30 lb. fresh slaked lime, 6 lb. tallow, 3 lb. lampblack and 12 lb. resin, and one recent "Angus Smith's solution" consisted of $3\frac{1}{2}$ parts coal tar, $\frac{1}{2}$ part coal oil, and one-half part pitch. The method of using the solution also varied considerably and attempts were made to keep the solution up to the original composition by adding quantities of the more volatile constituents to the tanks in which it was kept continually hot, with, it was to be feared, not a great element of success.

He thought, also, that a very great deal of trouble was due, at the present time, to the class of iron of which the pipes were being made. He had had pipes which had been laid at a much later date than the specimen he submitted, and taken out in such a condition that it was easy to cut a hole right through with a penknife. This softening of the metal was a thing of which he had heard no satisfactory explanation, and he would be very interested to know whether the author had found it to be a result of chemical or electrical action, or

Mr. Needham a combination of the two, for he had seen and handled pieces of pipe which had been lifted and which were no heavier than an equal volume of retort carbon.

In regard to the reinforced concrete pipe, the author had dealt only with the large sizes, which were not required to carry the number of connections from it, which one would have to use in distribution. Mr. Needham considered that there were many objections to the use of concrete pipes for distribution mains, because of the undoubted difficulties and expenses of making connections for other mains and services and such other appurtenances, which had to be laid after the main had been installed as a straight running length. These were difficulties which had not been dealt with very freely by the exponents of these pipes.

With reference to the lining of cast-iron pipes that was quite an interesting suggestion, and the author went on further to say that the outer skin of those pipes should be protected in some way against corrosion and suggested dipping. It appeared to him possible that there would be a source of trouble in the different coefficients of expansion between the metal and the concrete, causing them to separate one from the other, which would be fatal in allowing the water between them. It occurred to him that possibly the cement gun, which the Americans were using for very many purposes, might be usefully applied after the pipes were laid and jointed.

Certain of their critics from other branches of the profession, when they read the third paragraph on page 280, would think that the designing of these aqueducts was purely a rule of thumb procedure, and in fact it must be so, to a large extent, when they had so many unknown quantities present. Within certain limits one must err on the big side, and he had, on more than one occasion, to be thankful that his predecessors had added a very considerable margin to the calculated sizes of their pipes, even after allowing for all contingencies.

He was certainly very curious, in the same way as the author, to see and handle the centrifugally made cast-iron pipes, and he hoped that it would not be very long before they had something which would be an improvement on the cast-iron pipes of to-day, which were, in his opinion, a long way from being the ideal material for a pressure aqueduct.

Mr. Thomson Mr. CARRUTHERS THOMSON remarked that on page 290 the author said that: "the recent American practice of stemming metal "pipe joints with cement has very much to recommend it." He took it that, generally, it was cold water, and the pressure was not much

above the normal. Now if they had a manhole joint in a boiler which was so bad that they could not make a decent joint of it, they used cement, they had no trouble with it, and he did not see why it should not stand as well in any cold water pipe. There was nothing to hinder it; if the cement pipes would stand the other shocks surely it would stand at the joints. He did not know much about the life of the cast-iron pipes; the first thing he knew about pipes was when the Glasgow water pipes were laid. He remembered, when a boy, running before they were laid, through one of the pipes of about 3 feet diameter, which passed over Garnet Hill, one of the steepest places in Glasgow. He lived in the same street 32 years, and so far as he could remember those pipes had never given the slightest trouble. He supposed that the Glasgow water was not worse than the Vyrnwy water, if not a bit better. They were under the same conditions.

Mr. Thomson

On page 280, he saw that the bad practice had been used, apparently, of putting in sluice valves in the main of much smaller diameter than the mains. He thought that the engineer that did that must have been asleep, to say the least of it, especially if there was any chance of putting in a scraping machine to clean the inside of the pipes. In reference to the eating away of the metal, he thought that with ordinary decent water the difficulty in some cases must be electrical, because, if they took a joint in a steel, wrought iron, or cast-iron pipe, they found that there was a little bit of difference in the corrosion of the two pipes, and he thought that was due, to a certain extent, to the different material, of which they were made, setting up electrical action. He did not see why concrete pipes, if properly made, should be ruled out in a great many cases. He did not believe in leaving semi-concrete or metal pipes unprotected, because, if they did, it was only a question of time before the eating away of the outside would be such that the inside would not stand the pressure.

Mr. R. F. BAKER thought that the author had given them a very valuable paper in which he had touched upon the question of economy, which was a most important point. If engineers were to carry on they had to study economy. He was afraid that in the past a good many engineers had been guilty of extravagance, and he thought that it was time that they carried out useful works and not monuments. In regard to the question of the various forms of pipes it seemed to him to be simply a question of the comparative cost. If the reinforced concrete pipe could be produced cheaper than the iron or steel pipe, it was going to replace the iron and steel pipes, but it seemed to him that if somebody could produce some effective form of coating for the

Mr. Baker

Mr. Baker steel pipe, then the concrete pipe had its work cut out to hold its own. The author had taken all the wind out of their sails with regard to discussion, as he had put the case so thoroughly from both sides and had given the arguments for and against. Although the reinforced concrete pipes were not new, they knew that they had been used in this country for a good many years, he did not think that there were very many big pipes, and experience was the thing that they wanted. Engineers were therefore all looking to the author and others to tell them what was the right thing. It seemed to him that the weak spot was the joint. Of course they had the manufacturer's reply that the joints were not weak, but without practical experience of them, they certainly appeared to be the weakest point; he therefore thought that these concrete pipes were more suited for cases where there were not heavy pressures, and they would probably be more useful to a sewage engineer than to a water engineer.

He had had considerable experience of the construction of very large sewers, and in one case he had laid a cast-iron sewage pumping main 6 feet in diameter. That was a case where the reinforced concrete pipe would be very valuable, more especially because they got with the sewage a big scour at the bottom of the pipe from grit and other material. He knew of one case at the present time where a sewage pumping main was being put down which had the invert of the pipe thickened. Of course that could be very easily done with reinforced concrete. It was not a very good thing to have a circular pipe with more metal at the bottom than at the top, but still it was being done to allow for the scour on the bottom of the pipe. He liked the idea of lining the inside of the pipe as suggested by the author. It seemed to him that had a great future before it. A good number of the large sewers in London were built on the system of a tube railway with the ordinary tunnel segments, then they were lined internally. Of course these sewers had not to stand much pressure, but they did get surcharged up to, say, 30 feet head. The internal lining was put in between the flanges of the segments and he had never heard of any trouble having arisen through the concrete coming away from the metal.

Coming to the question of construction, he did not think that one point had been raised, which was the question of time, and he would like to ask whether they could construct works as quickly, using the reinforced concrete pipes, as they could if they were using iron or steel. Waterworks engineering had always struck him as being rather slow. He was brought up as a waterworks engineer and he had then

deserted it for a time for tunnelling, but he had come back to it, and he thought that was a criticism one had to make against waterworks engineering. - Now if this reinforced concrete work was going to take longer than the ordinary iron and steel work, it was not going to help them very much. If they had to wait, as they did in Italy, until the temperature was right, they might never get their work done. He thought that was one point that must be specially borne in mind.

Mr. Baker

Mr. R. E. GIBSON had listened with deep interest to the author's paper. He had had practically no experience with water mains, but a certain amount of experience with mains for conveying gas. They had had their troubles with deposits in gas mains, but not to the extent described by the author in connection with water mains. Thirty-five per cent. loss in capacity was a very serious matter. Their difficulties had been overcome to a large extent by coating the inside of the mains with oil. The oil was injected into the mains in the form of a fine spray and carried forward by the gas flowing through the main. The inside of the pipe became thoroughly coated with a film of oil, thus protecting the pipe and preventing deposit.

Mr. Gibson

He presumed it would be impracticable to treat water mains in this way, but if it were possible such treatment would no doubt be effective, as it had certainly cured a great deal of their trouble. He had always been a great believer in cast-iron for underground mains, but the paper had made him think in other directions. He could testify to the very long life of cast-iron pipes. He knew of cases where cast-iron mains, 40 or 50 years old, had been taken out of the ground and had been found to be practically as good as new, although they were without any coating on the outside. A great deal depended upon the nature of the material surrounding the pipes.

He would like to ask in regard to the centrifugally made cast-iron pipes, if the author could tell them briefly as to how the pipes were made. He would also like to ask whether "Bonna" pipes had been used for the conveyance of gas.

Mr. G. A. DICKIE stated that he had been troubled with rust in certain cases; and a process had been brought to his notice, at the Machinery Exhibition, held at Olympia, in September, 1920, for the electrical deposition of suitable metals to protect surfaces against rust. The process, he thought, was, relatively, a cheap one and might possibly be worth investigating.

Mr. Dickie

Mr. H. N. GILES was of opinion that the idea in the Kalgoorlie supply was that if they could keep every particle of air out of the water before it entered the main, and also prevent the air getting into the main

Mr. Giles

Mr. Giles afterwards, then the tubercular growths would be largely prevented, but it seemed to him that in the case of an old main, where they were going to have the water off for frequent periods, it was practically impossible to keep all air out, because he presumed that the air valves of ordinary type would be quite unsuitable for this. On page 282, there was the statement that "steel possesses far superior qualities to cast-iron for pipe making." Well, that of course, was true with the interior part of the pipe, but what about the exterior of the pipe? It was true that they were not troubled with nodules, but they had climatic and chemical influences to contend with, due to salts in the soil, &c. Now on the Vyrnwy line there were practically no steel pipes but they had a great many steel girders and valve covers, &c., all of which were on the second line. On the first line they were entirely cast-iron. The cast-iron ones had been in for over 30 years and they were as good as when they were put in, but the steel ones on the second line had deteriorated, so that in some cases the steel was now only half its original thickness. He supposed that it would be said that they were not treated correctly in the first instance, but was it possible to treat the exterior of a long length of main in a thoroughly effective manner and should it not be considered in making comparison between the cast-iron and steel mains. He gathered that the experience at Coolgardie, where 80 miles of main was buried and taken up again, rather went to show that the exterior was the cause of a good deal of trouble. He would also be very glad if the author could give them his experience as to what was the best way to treat steel or wrought iron surfaces which had *commenced* to rust, such as those covers which he had referred to. He believed that the best way was to scrub them thoroughly with steel brushes and then to apply a coat of thick red lead oxide paint, not iron oxide paint, with a stiff brush, so as to rub any remaining particles of rust into the paint, and then give them a good coating of gas tar.

On page 282, it was stated: "no ordinary fresh waters have a destructive effect upon concrete, if the cement from which it is made is "sound and the concrete itself well made." Should not that statement be qualified by saying "if the aggregate of the concrete was composed of suitable material." Was it not a fact that on the Thirlmere line the slightly acid water affected the mountain limestone used in the concrete, and a good deal of trouble ensued. With regard to the Frankfort incident; he happened to be there some 10 years ago and he believed that the incident referred to occurred when he was there. There was a small reservoir and he went up with the engineer who told him of the

trouble that they were having. It was with the 1 to 1 $\frac{3}{4}$ rendering of the concrete, and the engineer put it down to the extraordinary acidity of the water, not to the concrete. It also affected the pipes and they were treated with carbonate of lime. Nearly all the water for Frankfort at that time was taken from the gravel and sand beds, which formed the Taunus range of hills, or from the Glacial or Tertiary sand beds below these, but he understood from the engineer that the small reservoir was the only case in which they had the trouble with the concrete, and they found that the water was different to the other waters tapped. He had with him a photograph of this Frankfort reservoir for inspection.

Mr. Giles

The AUTHOR, in reply, said that he would endeavour to deal with the questions which they had put to him, but there were some posers. With reference to what Mr. Lancaster had said, he appreciated his point about the comparison of cost. He was afraid that he did not limit the comparison sufficiently; he admitted that there was a great deal of skilled labour in the manufacture of both cast-iron and steel. He rather had in mind one or two forms of reinforced concrete pipes which, to his mind, did not appear, from what he had seen of their manufacture, to involve quite the amount of labour that the "Bonna" pipe did; whether that was going to count as a factor against the "Bonna" pipe was a point against which he had tried to guard himself. After all, costliness was a relative matter, and relative to the end they wished to achieve, and if the extra amount of labour, which he thought the "Bonna" pipe involved, resulted in a better pipe, it would not lead to the detriment of the "Bonna" pipe. As regards the coefficient of rugosity of ferro-concrete compared with cast-iron and steel, he had been rather disappointed. He had, as a matter of fact, just finished laying a length of "Bonna" pipe of 60 inches diameter, and he had hoped before that evening to have had it under pressure and to have given some figures relative to it. He might, however, mention that Professor Stephen Dixon had told him a few days before that someone had been experimenting with both cast-iron, steel, and reinforced concrete pipes, and it was found that if anything the concrete pipes had a better coefficient of rugosity than either steel or cast-iron. It sounded rather a big thing to say, but he did not know the conditions or the kind of pipes and did not think that in the end there would be found a very great deal of difference between a *new* reinforced concrete and cast-iron or steel pipes. He could not help repeating that that was so only in the early stages and in a very short time comparison between the two would be entirely out of the

The Author

The Author question. Reinforced concrete was bound to maintain its discharge capacity very much better than either cast-iron or steel. With regard to the question of expansion and contraction he rather had in mind that, although in this country it did not trouble them seriously, any people who had long mains to deal with knew that the question of temperature, although their range of temperature was not great, was a matter that did give trouble and he had had cases of failure due to expansion. The expansion of steel and concrete was much alike, and he thought that there was a little lack of appreciation of this in the consideration of reinforced concrete mains. In the Pouilles Aqueduct there was no provision whatever for expansion or contraction; as a matter of fact a great many of the reinforced pipes were made without any joints at all, and were built up into a long continuous aqueduct. As regarded subsidence, he was afraid that he was not actually conversant with any cases in which reinforced concrete mains were involved. Most of the instances he had heard of, regarding the "Bonna" make, were ones where they had carried over an extraordinary amount of subsidence. The President had spoken to him, however, about a subsidence of 30 feet extending over at least a mile or two; he could not picture even a "Bonna" main carrying over that. The cast-iron pipes laid there had adjusted themselves apparently to these conditions. He thought that the difference between pipes made many years ago and those made within the last 20 or 30 years, lay in the fact that the former were "old" pipes, made of better metal and under better conditions than modern pipes. Pipes put down 60 years ago did seem to stand under the action of water and bacterial action in an extraordinary manner, but there could be no question about it, the modern cast-iron and steel pipes did not stand the same way; they corroded very rapidly, and what he was trying to find was something to take their place or to protect them. Of course there again with reference to Dr. Angus Smith's composition, even when it was properly made, it was essential that it should be also properly applied. Whether the softening mentioned by Mr. Needham was due to electrolysis or chemical action it was almost impossible to say. He was talking to an eminent chemist and said: "as far as I am concerned our pipes at the aqueduct do not suffer from electrolysis," but the chemist said "I would not say that, there are so many erratic currents about that you cannot with safety say that anything is not due to electrical action." With reference to Mr. Needham's remarks as to branches from the main, he did not think that there was really any difficulty; certainly reinforced concrete pipes had not been used for town work,

but personally he did not see any difficulty whatever. One would not use reinforced concrete pipes for very small mains, but for the ordinary branches and valves on large mains, there was no more difficult work in designing these for reinforced concrete pipes than for cast-iron and steel. With regard to the suggestions about coating the exterior of the pipes, he had said that the exterior of the metal pipe must be protected. In this country they did not suffer to the same extent from the acids in the ground as they did in some other countries. In South Africa the life of a cast-iron main was only about six or seven years, not due to the water flowing through but to the acids in the ground, and on that account they had been driven to use reinforced concrete pipes to a much greater extent than they had dreamed of in this country, but the efficient protection of the exterior of any metal pipe was to his mind absolutely essential. He did not know why, but he had found that there was a great prejudice in this country against the concrete gun. It had been used largely in America and it was quite a good thing, and a protective coating of cement could be applied quite easily and cheaply to cast-iron and steel pipes *in situ* with the gun. The Author

Mr. Carruthers Thomson had been a little severe on the engineer who put in valves of smaller diameter than the main. He had his reason; he was saving expense, and so far as the flow was concerned he was not interfering with that. The loss of head through properly designed valves was inconsiderable and the saving in cost was very considerable. He, however, had not had the maintenance engineer in mind, and their trouble in Birmingham was that they could not clean or brush out their mains mechanically, because they were cut up in small sections by valves of a smaller diameter.

Reinforced concrete pipes appeared to have a very great future for sewage works, but there, again, one had to consider what was the nature of the fluid that had to pass through, because sewage contained acid which the ordinary water did not contain, and that might be very destructive in some cases and an engineer must be very careful before he used concrete, pure and simple, for sewers. As regarded the rate of construction, he did not think that there was anything in it; every pipe took a certain amount of time to make, reinforced concrete, cast-iron, or steel. It was a matter of the average rate of laying. There ought to be no difference in the rate at which cast-iron, steel and concrete pipes were laid, and the only difference was that concrete required a little time—perhaps a fortnight or three weeks—before it could be handled in safety and it ought to have that start. Given

The Author that, it was a matter whether the manufacture kept pace with the speed at which they wished, or were able, to lay the pipes.

With reference to Mr. Gibson's remarks as to gas mains being coated with oil, he was afraid that they could not do that very well with water mains. The oil, probably, would not stay there, but would come off and be unpleasant in the water. He was now trying an experiment, as he had seen it stated that in America they had found an efficient protection of the inside of a cast-iron main by painting it with cement and oil, so he had put some on the interior of a pipe. The water had been in the pipe for some time, but he had not seen it before he came to the meeting, so he did not know whether the coating had remained or not.

He was afraid that he could not describe the centrifugal method of making cast-iron pipes very closely; he had not seen it done, he had a description given him of one way in which it was done, and it was a little difficult to explain, but he would endeavour to pass on the description that was given to him. The mould of the pipe was metal and jacketed for cold water. That was on a travelling carriage of some sort on which the mould was made to revolve and at the same time a ladle was filled with the quantity of molten metal which was required for the single pipe. He gathered that there was a long channel through which the metal flowed at a given speed, so that there was an even riband of metal poured in spiral form into the moving mould. At the same time the mould was revolving at a high speed so as to keep the metal pressed out by centrifugal force. This was a very rough description, but he thought that it would perhaps convey something to their minds.

One hoped that probably something more satisfactory than ordinary cast-iron might be found in that direction. He did not know how far the Kalgoorlie line stood the test of time, he only quoted from the paper that was read before the Institution of Civil Engineers when, he thought, it was in its infancy. It seemed to him exceedingly difficult to extract all the air from water that was passing through a long aqueduct. About the protection of cast-iron covers and doors, he was afraid that was a very difficult problem. Concrete in that case would not be a good protection and there was nothing but paint to prevent rust. He had on the Elan Aqueduct 8 feet diameter steel tubes, and with all the painting and scrubbing he had done, it was a difficult thing to protect them. He thought of surrounding them with a light skin of reinforced concrete, but when it came to covers he advised sticking to cast-iron.

He was much interested to hear from Mr. Giles about the Frankfort water, he was glad to hear that it was the acid water that was to blame. He was only brought into contact with it through the bituminous paint that was used at Frankfort to protect the concrete, and thought that it was a very good thing that they were not troubled with water of that kind in this country. The Author

CORRESPONDENCE.

Mr. L. HOLME LEWIS considered that in view of the changed conditions brought about by the War, in their bearing on the cost of new construction, the author had very properly directed attention to the need for exercising strict economy in design. It had to be admitted, when they looked at some of the works carried out during the past 60 years or so, that it was practicable to obtain equal utility and dependability at substantially less cost, and it was the duty of engineers to make the most efficient use of the materials at their disposal, but this did not necessarily involve any sacrifice of security. The physical properties of materials employed in engineering construction were better known to-day than in the time of their predecessors, and strength could therefore be more accurately calculated. In order to ensure both economy and efficiency, what the engineer had to study was the most suitable material to adopt and the correct disposal of strength. Mr. Lewis

Cast-iron pipes for the conveyance of water under pressure had held sway over other modes of construction for a long period and had on the whole given good results, but in recent years wrought steel had proved a real and formidable competitor, and now reinforced concrete promised to become a serious rival to iron and steel.

He entirely agreed with the author's conclusions that wrought steel was preferable to cast-iron for large water mains, particularly in situations where they were likely to be subject to shocks. Steel pipes were either "riveted" or "welded," and he presumed that the author had in mind the latter type of construction which was superior and more economical than the riveted type.

The principal drawbacks of iron and steel pipes were fully and clearly stated by the author, but Mr. Holme Lewis' own observations led him to think that the diminution in carrying capacity, due to internal incrustation, was not quite so serious as indicated in the paper, and that further investigations were necessary to arrive at the true rate of diminution from this cause.

Mr. Lewis The results of experiments on certain siphons forming parts of the Thirlmere Aqueduct of the Manchester Corporation, made by Mr. A. A. Barnes, were, he felt sure, accurately recorded, but he was of opinion that proper allowance was not made for the effect of corrosion on the functioning of mechanical appliances, &c. For example, it had been ascertained, since the experiments were made, that reflux valves and the hinged doors on the Southern end of the siphons exercised a marked influence on the carrying capacity. Diminished discharge, at first thought to be due to internal incrustation, had also been traced to local accumulation of silt in places where the pipes had sharp vertical deviations. A flow test that did not take all the circumstances into account could not be regarded as a true measure of the internal incrustation, and he must confess that in the face of his own observations, he was unable to accept the figures that had been published, purporting to represent the falling off in the discharging capacity of pipes by reason of incrustation.

He was quite satisfied that at no time had the pipes on the Thirlmere Aqueduct of the Manchester Corporation diminished to the extent of 40 per cent. by reason of incrustation alone, and the evidence that he had been able to collect in other directions was consistently in favour of the opinion that there was a limit to the growth of incrustation, which was reached when the crust was of sufficient thickness to discontinue the supply of iron to sustain bacterial life. This view was supported by the fact that the rate of growth of incrustation was at first rapid, but gradually diminished as it gained in thickness.

The ultimate thickness would probably vary to some extent according to the character of the water, but according to his experience it rarely exceeded $1\frac{1}{4}$ inches, which in a 40-inch pipe was a reduction of about $18\frac{1}{2}$ per cent. in sectional area. A 40 per cent. reduction in a 40-inch main would mean a crust thickness of over 3 inches.

The carrying capacity of the first pipe line from Lake Thirlmere, which was 40 inches in diameter, was not tested when new, but was estimated at about 11 million gallons per day. When it had been in use for 10 years its carrying capacity was 9 million gallons per day, or 18 per cent. less than the estimated original capacity. The second pipe line was 44 inches in diameter. When new and clean it was estimated to be capable of conveying about $13\frac{1}{2}$ million gallons per day. Immediately before a start was made with the cleaning of these pipe lines, in 1914, when one of them had been in use 20 years, and the other about 10 years, the two lines were conveying a little over

20 million gallons per day, thus showing a reduction on the estimated original capacity of nearly $4\frac{1}{2}$ million gallons per day or 18 per cent. Mr. Lewis

A third pipe line was brought into commission in February, 1914. During that year the first and second lines were cleaned internally between Thirlmere and Middlebrook, a total length of about $32\frac{1}{2}$ miles. Assuming the mechanical appliances, such as automatic valves and reflux valves, did not restrict the flow of water, the three pipe lines would convey, when in a clean state internally, about 38 million gallons per day. They were at present conveying an average of 30 million gallons per day or a reduction of 21 per cent. The $32\frac{1}{2}$ miles consisted of 29 separate siphons, most of which were capable of conveying 32 million gallons per day. It might therefore be assumed that the diminution due to internal incrustation was about 16 per cent., and that the fall in the capacity of the siphons, which were only capable of conveying 30 million gallons per day, was attributable to other causes than incrustation.

The two pipe lines (36-inch and 40-inch) from Middlebrook to Prestwich Reservoirs, Manchester, which were $12\frac{1}{2}$ miles in length, were originally capable of conveying 25 million gallons per day. Their present capacity was 20 million gallons per day or a reduction of 5 million gallons per day, which was equivalent to 20 per cent. These two pipes had not been cleaned since they were laid. One had been in use about 27 years and the other about 17 years. There had been no diminution in their carrying capacity for about 10 years.

A 30-inch main from the Longdendale supply of the Manchester Corporation, laid in 1865, when examined about 8 months ago, was found to have an incrustation of rather under one inch in thickness, which, in a 30-inch pipe, represented a reduction of about 13 per cent. in sectional area.

He gave those figures not because he was wedded to iron and steel pipes, but merely to show that there was need for further investigation in order to assist engineers in making a reliable comparison of the relative merits of iron and steel pipes, and reinforced concrete pipes. The principal disadvantages of the latter type of construction were enumerated by the author. To these might be added the extra cost of laying, due to greater thickness of walls and longer joint holes, which involved additional trench excavation. At the present time steel pipes to give equal service could be laid at substantially less cost, but he was of opinion that if manufacturers would only apply themselves to improvement in the methods of manufacture, they would be able to produce at a price that would compete successfully with iron

Mr. Lewis and steel pipes, and it was in the interest of water engineers to encourage this development as much as possible.

The Author The AUTHOR, in reply to Mr. Holme Lewis, wished to thank him for his interesting communication. The question of the rate of incrustation of cast-iron mains had always been a matter of great importance, and the author had regarded the published account* of the Thirlmere figures as being very valuable. Apparently Mr. Holme Lewis was in error in his surmise that valve resistances, &c., had not been allowed for, as it was there stated that the *net* hydraulic gradient was obtained. It could not be too strongly repeated that this true hydraulic gradient must be found in each case, as steeper gradients could often be obtained by a process of "heading-up," at many of the siphons and the discharge thereby increased. These steeper gradients could not be maintained later for larger flows as the tail-water rose, and they must therefore be found for each particular case before the actual incrustation could be ascertained.

An example of this was given in Mr. Holme Lewis' own figures for the three existing lines; the longer siphons had lost 21 per cent. of their carrying capacity in seven years, seeing that they could only convey 30 m.g.d. instead of 38 m.g.d. No doubt the shorter siphons *at the same gradient* had lost the same amount, but owing to the steeper gradient which *could* be obtained in these cases they *would* be capable of conveying 32 m.g.d. if not restricted by the necessary flatter gradients of the longer siphons.

The author, must however, take exception to the principle of estimating the loss due to incrustation by means of the diminution of area caused by the actual nodules. Percentage losses in delivering capacities had been found in many pipe lines to be far greater than could be explained by this means, and it was proved beyond all doubt that the loss of head by friction was due to the eddies set up at the nodules themselves. Accumulations of so-called "silt" in a siphon must as a rule also be debited to the loss due to incrustation, since in most cases this "silt" was composed of broken up nodules transported by the water from upstream portions of the siphon and deposited at the foot of slopes. Scour valves had very little effect in the way of emptying this detritus, as owing to its compact mass and weight it was not easily moved after accumulating.

* Proc. Inst. C.E., Vol. CCVIII. Barnes on the "Discharge of Large Cast-iron Pipe Lines in relation to their age."

ANNUAL GENERAL MEETING,

27th April, 1921.

J. R. DAVIDSON, C.M.G., M.Sc. (*Vict.*), M.Inst.C.E.,
President, in the Chair.

The Council reported that the following elections had been made:—
ALFRED WALLACE MINARDS, as *Associate Member*; and JAMES KENNETH
WILKIE, as *Student*.

The scrutineers of the ballot reported the election of the Officers and
Council for 1921-1922 as follows:—

President—

JAMES B. WILKIE, M.I. Mech. E., M. Inst. N.A.

Vice-Presidents—

Professor T. B. ABELL, O.B.E., M. Eng. (*L'pool*), R.C.N.C. Ret., M. Inst. N.A.

RALPH E. GIBSON, M. Inst. C.E.

Members of Council—

J. E. LLOYD BARNES, Wh. Sc.,
M.I. Mech. E.

WILLIAM BRODIE, M. Inst. C.E.

W. J. WILLET BRUCE, O.B.E.,
M. Inst. N.A., M.I. Mar. E.

JOHN DYKES, M.Inst.N.A., M.I. Mar.E.

Professor W. MASON, D. Sc. (*Vict.*),
Assoc.M.Inst.C.E., A.M.I.Mech.E.

W. E. MILLS, F.S.I.

C. A. NEEDHAM, A.M.I. Mech. E.

B. G. OXFORD, Wh. Sc., M. Inst. N.A.,
M.I. Mar. E.

H. S. ROWE, B. Sc. (*Lond.*),
Assoc. M. Inst. C.E.

A. T. WALL, O.B.E.,
A.R.C. Sc., M. Inst. N.A.

Eng.-Capt. J. T. H. WARD, C.B.E.,
M.V.O., R.N. Ret., M. Inst. N.A.

Professor W. H. WATKINSON,
M. Eng. (*L'pool*), M. Inst. C.E.,
M. I. Mech. E., M.I.E.E.

*Honorary Solicitor—*ERNEST W. PIERCE.

*Honorary Librarian—*BERNARD RATHMELL, M.I. Mech. E.

Honorary Treasurer—

Professor E. W. MARCHANT, D. Sc. (*Lond.*), M.I.E.E.

Honorary Secretary—

Assoc. Professor T. R. WILTON, M.A. (*Cantab.*), M. Inst. C.E., M. Cons. E.

REPORT.—XLVII SESSION.

1920-1921.

(From 3rd November, 1920, to 27th April, 1921.)

At the close of the XLVII Session the retiring Council presented the following Report upon the state of the Society.

THE ROLL OF THE SOCIETY.

The additions to the Roll of the Society at the close of the Annual General Meeting on 27th April, 1921, excluding transfers, have been 58, as compared with 103 in the previous Session—comprising 25 Members, 5 Associate Members, and 28 Students, while, in addition, 4 Students have been transferred to the class of Member and 1 Student to the class of Associate Member.

There have been 30 names removed from the Roll, compared with 19 last Session. Of these, 6 have died and 24 have resigned or have been removed from the Roll in accordance with Rule III.

At the present time the Roll of the Society stands at 705, made up as follows:—5 Honorary Members, 511 Members, 40 Associate Members, 36 Associates and 113 Students.

THE SESSION AND MEETINGS.

The Session was opened on the 3rd November, 1920, by the President, J. R. Davidson, C.M.G., M. Sc. (*Vict.*), M. Inst. C.E., who delivered his Inaugural Address, dealing with the Past and Present Conditions of Water Supply.

The Address was succeeded at subsequent Meetings by Papers and Discussions on various Engineering subjects, as follows:—

1920.

17th November—C. K. ATKINSON.

“The Prevention of Accidents in Industry.”

1st December—G. KENYON BELL, Assoc. M. Inst. C.E.

“The Design and Construction of Large Commercial Fuel Oil Depôts.”

15th December—W. D. KIRKPATRICK, M.I.E.E.

“Sound in Engineering and Navigation.”

1921.

5th January—W. J. E. BINNIE, B.A. (*Cantab.*), M. Inst. C.E., F.G.S.

“Water Power Problems.”

19th January—Professor W. MASON, D.Sc. (*Vict.*), Assoc. M. Inst. C.E.,
A.M.I. Mech. E.

“Impact Tests.”

2nd February—R. F. BAKER, M. Inst. C.E.

“Tunnelling in Water-Bearing Strata.”

16th February—A. P. ROSS, M. Inst. C.E.

“Urban Passenger Transport by Train.”

2nd March—CHAS. F. FARRINGTON, A.M.I. Mech. E.

“Cowlyd Waterworks.”

16th March—G. LAIRD LYLE, M.Inst. N.A.

“General Remarks on Practical Merchant Ship
Construction and Repairs.”

30th March—F. W. MACAULAY, M. Inst. C.E.

“Considerations on the Choice of Materials
for Pressure Aqueducts.”

13th April—The Lecture by Commodore Sir FREDERICK YOUNG, K.B.E.,
R.N.R., M.I. Mech. E., on “Ship Salvage during the
late War,” was postponed owing to the industrial dispute
preventing Sir Frederick Young being present.

STUDENTS' SECTION.

The Inaugural Lecture of the Session was given on Thursday, 18th November, by Sir Westcott S. Abell, K.B.E., M.Eng. (*L'pool*), M.Inst.C.E., M. Inst. N.A., R.C.N.C. Ret., who dealt with the functions of a Students' Section of an Engineering Society. This Address will be found printed in the “Transactions” for the Session.

The other Meetings of the Section were as follows:—

1921.

6th January—J. HAWLEY PENNINGTON.

“Sugar Manufacturing and Refining Machinery.”

3rd February—* F. ONIONS.

“Oil Fuel Equipment for Locomotives.”

3rd March—J. H. RYDER.

“Autogenous Welding.”

7th April—VICTOR LOCKNEY.

“Water Tube Boilers in Marine Practice.”

The Council are gratified at the high standard of the Papers read and hope that Students of the Society will take full advantage of these special Students' Meetings.

* The Students' Prize was subsequently awarded to F. Onions for this Paper.

COMMITTEES AND OTHER ACTIVITIES.

Municipal Technical School.

Mr. F. E. Cooper has again represented the Society on the Committee of the Municipal Technical School.

British Marine Engineering Design and Construction Committee.

Messrs. W. J. Willett Bruce, O.B.E., S. B. Freeman, C.B.E., J. Hamilton Gibson, O.B.E., and Jas. B. Wilkie, have continued to represent the Society on this Committee, while Mr. J. Hamilton Gibson has also acted on the General Purposes Committee.

The Committee in continuance of their work in the previous year have almost completed Rules for Water-Tube Boilers, Pipes and Shafting.

The Rules for Marine Cylindrical Boilers have been adopted, after slight amendments, by Lloyd's, Bureau Veritas, the British Corporation and the Board of Trade.

DERBY GOLD MEDAL.

The Derby Gold Medal has been awarded for the 1919-1920 Session to Mr. John Watson, *Member*, for his Paper, entitled:—"Marine Propelling Shafting, Bearings and Supports," read before the Society on the 3rd December, 1919.

The following are the conditions as to the Award of the

Derby Gold Medal:—

- 1.—The Medal to be called the DERBY GOLD MEDAL.
- 2.—The Medal to be awarded annually to the author of any paper read during the Session, which a Special Committee, appointed by the Council, consisting of the President, three preceding Past Presidents (ex-officio Members of the Council), and the Honorary Officers of the Society, may select as most worthy of such distinction.
- 3.—The Members of the Committee at a Meeting called for the purpose, shall express their selection by vote, and in case of equality of votes the Chairman shall have a casting vote.
- 4.—No Member of the Committee, having himself read a paper during the Session, shall take part in the adjudication.

SOCIETY'S PREMIUM.

The Council decided that the Society's Premium for the same Session should be awarded to Mr. E. A. Atkins, *Member*, for his Paper, entitled :—"Steel Wire and Wiredrawing," read before the Society on the 18th February, 1920.

*The following are the conditions as to the Award of the
Society's Premium :—*

1.—That the Special Committee, consisting of the President, three preceding Past Presidents (ex-officio Members of the Council), and the Honorary Officers of the Society, appointed to award the DERBY GOLD MEDAL, be requested to make a recommendation annually to the Council as to the award of the Society's Premium to the author or authors of any paper or papers read during the previous Session which the Committee may consider worthy of such recognition.

2.—No Paper, the author of which is a Member of the Council or for which the DERBY GOLD MEDAL is awarded, shall be eligible for the Society's Premium.

3.—The Premium shall, subject to the approval of the Council in each case, be presented in the form of books or other articles which may be selected by the author of the paper as useful to him in his profession.

4.—The value of the Premium shall in any year be such sum as the Council may prescribe not exceeding the sum which shall have accrued from the investment of the Society's Premium Fund and to be available for the purpose.

"TRANSACTIONS."

The publication of the "Transactions" in Monthly Parts has been adopted, so that the information contained in the papers and discussions may be available to the general body of Members at the earliest possible date after the reading and discussion of any paper. It has not been possible to issue these as promptly, owing to arrears of previous years, as it is hoped will be done in future Sessions.

ANNUAL DINNER.

The Annual Dinner was held at the Exchange Hotel, Liverpool, on 27th January, 1921, about 220 Members and Guests being present.

Among the Guests were:—

The Lord Mayor of Liverpool (Alderman E. Russell-Taylor); Colonel J. Vaughan Campbell, V.C., C.M.G., D.S.O., A.D.C. (Commanding Liverpool Infantry Brigade, T.F.); Lieut.-Colonel A. Buckley, D.S.O., M.P.; Thos. Rome, Esq. (Chairman of the Mersey Docks and Harbour Board); Dr. Adami, F.R.S. (Vice-Chancellor Liverpool University); L. A. P. Warner, Esq., C.B.E. (General Manager and Secretary Mersey Docks and Harbour Board); J. L. Williams, Esq. (President Liverpool Incorporated Law Society); T. Taliesin Rees, Esq., F.R.I.B.A. (President of the Liverpool Architectural Society); G. Hammond Etherton, Esq. (Town Clerk of Liverpool) and Honoratus Lloyd, Esq., K.C.

OBITUARY.

The Society has since the close of the last Session lost through death the following:—

Members.

H. S. Boumphrey.	J. B. Jeffrey.
T. W. Davies.	J. T. Rubery.
Henry Forbes.	William Sibun.

FINANCE.

In accordance with Rule VI, the Honorary Treasurer's Financial Statement for the year ending 31st December, 1920, subject to audit by Mr. F. W. Marsh, C.A., is presented herewith.

The finances of the Society had given considerable anxiety to the Council and rendered it absolutely necessary that the rates of subscription should be raised, and to give effect to the recommendations of the Council a Special General Meeting was held on 21st June, 1920, at which the Subscriptions were revised as follows:—

Resident Members, Associate Members and Associates—One and a Half Guineas per annum.

Non-resident Members, Associate Members and Associates—One Guinea per annum.

Students—Fifteen Shillings per annum.

University Students—Half-a-Guinea per annum.

Life Composition Fee—Twenty Guineas per annum.

These increased rates took effect on 1st January, 1921, and the Council are glad to record that the general body of Members, recognising the absolute necessity of raising the rate of subscription, have given every support to this change, and despite the higher rates of subscription the numbers of the Society show an increase.

ALTERATION OF RULES.

At a Special General Meeting held on 21st June, 1920, certain alterations in the Rules affecting the rates of subscription and procedure were made and these have been incorporated in the Rules of the Society.

THE LIBRARY.

The following Periodicals are sent to the Society :—

The American Marine Engineer	Machinery
Engineering and Industrial	The Machinery Market
Management	The Marine Engineer and
(Originally Cassier's Magazine)	Naval Architect
The Contractors' Record	The Mechanical Engineer
The Engineering Review	Page's Engineering Weekly
Gas and Oil Power	South African Engineering
Indian Engineering	The Steamship

The Library is generally open to Members of the Society every week-day, but the rooms are often used for examinations or bazaars, so that it is advisable that Members should, before going to the Institution to consult the Library, ascertain, by telephoning to the Curator, that the rooms are not occupied (Telephone 2770 Royal).

GROWTH OF THE SOCIETY.

The following Table shows the progress made by the Society since its commencement in 1875:—

Year	Honorary Members	Ordinary Members	Associate Members	Associates	Students	Total	New Members, Assoc. Members, Associates and Students Elected and Transferred	Deaths, Resignations, Transfers, &c.	Net Increase	President for each Session
1875-76	—	51	—	—	—	51	—	—	—	C. H. Graham Smith
1877	3	68	—	—	—	71	20	—	20	
1878	3	82	—	—	—	85	17	3	14	Robinson Souttar
1879	3	73	—	—	—	76	4	13	—	M. E. Yeatman
1880	3	88	—	—	—	91	23	8	15	Alexander Ross
1881	4	93	—	—	—	97	18	12	6	Alfred Holt
1882	5	88	—	—	11	104	10	3	7	Frank B. Salmon
1883	5	96	—	—	8	109	10	5	5	Henry Bramall
1884	5	99	—	—	6	110	16	15	1	R. Ratsey Bevis
1885	5	109	—	—	4	118	19	11	8	William E. Mills
1886	5	120	—	—	11	136	28	10	18	Coard S. Pain
1887	7	144	—	—	15	166	32	2	30	John J. Webster
1888	6	151	—	—	18	175	30	21	9	C. H. Darbishire
1889-90	6	169	—	1	16	192	33	16	17	Henry H. West
1890-91	6	181	—	3	9	199	20	13	7	F. Hudleston
1891-92	5	191	—	6	11	213	19	5	14	John T. Wood
1892-93	3	219	—	8	10	240	35	8	27	R. E. Johnston
1893-94	2	221	—	11	13	247	29	22	7	H. P. Boulnois
1894-95	4	238	—	11	21	274	41	14	27	H. S. Hele-Shaw
1895-96	6	278	—	18	20	322	61	13	48	A. J. Maginnis
1896-97	8	311	—	25	19	363	49	8	41	S. B. Cottrell
1897-98	10	325	—	28	20	383	26	6	20	George Farren
1898-99	10	338	—	33	21	402	45	26	19	John A. Brodie
1899-00	10	416	—	55	21	502	119	19	100	A. Bromley Holmes
1900-01	10	425	—	59	24	518	27	11	16	Sir J. A. F. Aspinall
1901-02	10	396	—	59	18	483	38	73	—	Arthur Musker
1902-03	9	417	8	63	18	515	43	16	27	Ernest S. Wilcox
1903-04	9	434	11	59	22	535	40	20	20	Thomas L. Miller
1904-05	9	421	17	55	26	528	42	49	—	Frank E. Priest
1905-06	10	418	22	54	22	526	37	39	—	J. Reney Smith

Year	Honorary Members	Ordinary Members	Associate Members	Associates	Students	Total	New Members Assoc. Members Students Elected and Transferred	Deaths, Resignations, Transfers, &c.	Nett Increase	President for each Session
1906-07	9	404	34	49	20	516	27	36	—	A. F. Fowler
1907-08	7	419	40	50	19	535	42	23	19	Thomas Duncanson
1908-09	8	424	39	47	20	538	29	26	3	A. R. T. Woods
1909-10	8	409	35	45	19	516	18	40	—	William Brodie
1910-11	8	406	36	44	49	543	55	28	27	Edward Allen
1911-12	8	432	37	43	56	576	57	24	33	W. J. Willett Bruce
1912-13	7	457	37	42	58	601	52	27	25	W. H. Watkinson
1913-14	6	455	35	40	63	599	30	32	—	F. E. Cooper
1914-15	6	462	39	36	62	605	32	26	6	E. C. Given
1915-16	6	448	36	31	61	582	36	59	—	E. W. Marchant
1916-17	6	446	36	29	55	572	25	35	—	Thomas M. Newell
1917-18	6	464	34	29	54	587	33	18	15	Harold Dickinson
1918-19	5	473	32	32	51	593	28	17	6	J. Wemyss Anderson
1919-20	5	509	35	37	92	677	112	28	84	J. Hamilton Gibson
1920-21	5	511	40	36	113	705	63	35	28	J. R. Davidson

The Society exchanges its Transactions with—

American Association for the Advancement of Science	Institution of Mechanical Engineers
American Institute of Mining Engineers	Institution of Municipal & County Engineers
American Society of Civil Engineers	Institution of Naval Architects
American Society of Naval Engineers	Iron and Steel Institute
American Society of Mechanical Engineers	Junior Institution of Engineers
American Society of Refrigerating Engineers	Liverpool Philomatic Society
Association of Engineering Societies, Boston, Mass., U.S.A.	Manchester Association of Engineers
Association of Engineering and Shipbuilding Draughtsmen	Manchester Geological and Mining Society
Association of Water Engineers	Manchester Literary & Philosophical Society
Barrow & District Association of Engineers	Mining Institute of Scotland
Bradford Engineering Society	North-East Coast Institution of Engineers and Shipbuilders
British Association for the Advancement of Science	North of England Institute of Mining and Mechanical Engineers
Bureau of Standards, U.S.A.	Royal Institute of British Architects
Cold Storage and Ice Association	Royal Institution of Cornwall
Concrete Institute	Royal Meteorological Society
Engineers' Club of Philadelphia, U.S.A.	Royal Philosophical Society of Glasgow
Engineers' Club of St. Louis	Royal Society of Arts
Engineering Association of New South Wales	Rugby Engineering Society
Engineering Institute of Canada (Incorporated with Canadian Civils)	Società degli Ingegneri e degli Architetti Italiani
Engineers' Society of Western Pennsylvania	Société des Ingénieurs Civils de France
Franklin Institute	Société Suisse des Ingénieurs et Architectes
Geological Institution, University of Upsala, Sweden	Society of Arts of the Massachusetts Institute of Technology
Huddersfield Engineering Society	Society of Engineers
Institution of Civil Engineers	Society of Naval Architects and Marine Engineers, U.S.A.
Institution of Civil Engineers of Ireland	South African Society of Civil Engineers
Institution of Electrical Engineers	South Wales Institute of Engineers
Institution of Engineers of Australia	Stevens Institute of Technology
Institution of Engineers of Australia, Perth Division	Surveyors' Institution
Institution of Engineers and Shipbuilders in Scotland	University of California
Institution of Gas Engineers	University of Illinois Engineering Experimental Station
Institute of Marine Engineers	Universidad Nacional de La Plata
	Victorian Institute of Engineers
	Western Society of Engineers

The Transactions of the Society are presented to—

Bootle Free Public Library	Liverpool Free Public Library
Cambridge University Engineering Dept.	Liverpool University Engineering Dept.
Chief of Engineers U.S. Army	Manchester Free Public Library
"Engineer"	Manchester University Engineering Dept.
"Engineering"	McGill University, Montreal
"Engineering Review"	"Mechanical Engineer"
Glasgow University Library	"Page's Weekly"
"Indian Engineering"	Patent Office Library

Total Number of Transactions exchanged with, and presented to,
other Societies = 80.

LIVERPOOL ENGINEERING SOCIETY.

Dr. STATEMENT OF RECEIPTS and EXPENDITURE to the 31st DECEMBER, 1920. Cr.

RECEIPTS.		£	s.	d.
To Subscriptions due 1st January, 1920.—				
328 Resident Members	£344	8	0	
169 Non-Resident Members	88	14	6	
18 Resident Associates	18	18	0	
10 Non-Resident Associates	5	5	0	
30 Resident Associate Members	31	10	0	
4 Non-Resident Associate Members	2	2	0	
5 Students	2	12	6	
55 University Students	13	13	0	
4 Life Members	63	0	0	
628				
Add Arrears from 1919	570	5	0	
	174	3	0	
	744	8	0	
Less Amounts in advance 31st Dec., 1919 £87 19 0				
" Subscriptions waived whilst on Active Service	29	7	0	
" Subscriptions written off	44	13	0	
" Arrears to 1921	135	6	0	
	297	5	0	
	£447	3	0	
Add Amounts in advance 31st Dec., 1920	66	19	6	
	514	2	6	
To Proceeds.—Sale of Papers, Binding Fees, &c. 91 18 4				
" Bank Interest, less Commission	7	3	1	
" Lord Derby's Donation for Gold Medal	10	0	0	
Due Lloyds Bank Limited	547	0	8	
Total	£1,170	4	7	

EXPENDITURE.		£	s.	d.
By Balance due Bank, 31st December, 1919				
" Royal Institution Rent to 14th February, 1921	£20	0	0	
" Hire of Bookcases	7	5	6	
" Postages and Stationery	27	5	6	
" Honorary Secretary, Petty Cash	11	13	3	
" " for Assistant Secretaries	60	0	0	
" " "	62	10	0	
" Assist. Treas. from 20th April, 1919, to 31st Dec., 1920	122	10	0	
" Audit Fee to 31st December, 1919	52	18	4	
" General Printing, Papers, Report, &c.	3	3	0	
" Reporting Meetings	241	5	11	
" Printing, Illustrating, and Binding Transactions (Volume XII)	39	17	4	
" Municipal Technical School Prizes	413	7	6	
" Loss on Dinner	694	10	0	
" "	5	0	0	
" "	26	7	0	
Total	£1,170	4	7	

I have examined the above Accounts with the Books and Accounts of the Society, and certify the same to be correct.

I have ascertained that the Certificates of the Preference Shares and Ordinary Stocks as mentioned above are deposited with Lloyds Bank Limited, Liverpool, and I have further verified the Balance at the Bankers.

Liverpool, 31st May, 1921.

(Signed) FRED. W. MARSH, Chartered Accountant.

LIVERPOOL ENGINEERING SOCIETY.

Dr. PERMANENT PREMIUM FUND, as at 31st DECEMBER, 1920. Cr.

CAPITAL ACCOUNT.

To Investment in £100 Buenos Ayres Great Southern Railway	
Ordinary Stock	Cost £126 5 0
By Balance at 31st December, 1920	£126 5 0

INCOME ACCOUNT.

To Premium Award—Season 1918-1914	£4 9 0
" Part " 1918-1919	2 3 5
	£6 12 5
" Balance in Lloyds Bank Limited	13 19 9
	£20 12 2
By Balance as at 31st December, 1919	£15 1 2
" Bank Interest allowed	0 13 0
" Interest on £100 Buenos Ayres Great Southern Railway Ordinary Stock to 30th June, 1920	4 18 0
	£20 12 2

HOUSING FUND, as at 31st DECEMBER, 1920.—Capital Account.

To Investments—	
50 6% Preference Shares Rangoon Electric Tramways Supply Co., Ltd.	Cost £254 6 0
£160 Ordinary Stock Buenos Ayres Great Southern Railway	Cost 199 8 6
£210 10s. 6d. 5% War Loan, 1928-1947	Cost 293 18 8
Balance in Lloyds Bank Limited	63 15 7
	£541 8 9
By Balance at 31st December, 1919	£507 11 6
" Dividend on 50 6% Preference Shares in Rangoon Electric Tramways Supply Co., Ltd. to 30th June, 1920—Less Tax	£10 10 0
" Interest on £210 10s. 6d. 5% War Loan, to 1st December, 1920	15 10 6
" Dividend on £160 Buenos Ayres Great Southern Railway Ordinary Stock, to 30th June, 1920, Less Tax	7 16 9
	£541 8 9

I have examined the above Accounts with the Books and Accounts of the Society, and certify the same to be correct.

I have ascertained that the Certificates of the Preference Shares and Ordinary Stocks as mentioned above are deposited with Lloyds Bank Limited, Liverpool, and I have further verified the Balance at the Bankers.

Liverpool, 31st May, 1921.

(Signed) FRED. W. MARSH, Chartered Accountant.

Students' Section.

4th November, 1920.

PROFESSOR T. B. ABELL, M. Eng. (*L'pool*), M. Inst. N.A.,
R.C.N.C. Ret., in the Chair.

INAUGURAL ADDRESS

BY SIR WESTCOTT S. ABELL, K.B.E., M. Eng. (*L'pool*),
M. Inst. C.E., M. Inst. N.A., R.C.N.C. Ret.

THE re-opening of the various phases of professional and intellectual activities after such a period of disturbance as the world has recently experienced, indicates that the spirit of scientific endeavour is anxious, once again, to advance the development of knowledge for the betterment of man.

But the conditions under which this work can be done are no longer the same, and it is not sufficient to attempt a solution of post-war problems by pre-war methods. Man is ever prone to put new wine into old bottles, and it is desirable for this and every Student Branch to endeavour to set its aim high now, in order to avoid the path of least resistance and to meet successfully the needs of the future.

One of the marked developments of this century has been the desire of the various professional Institutions to interest the younger members in their activities. This has not been entirely a matter of unselfish interest, but has been a decided gain to the Institutions themselves, as their membership and prestige have thereby increased and, in addition, the numbers have also enlarged, since the younger men take more and more care to become eligible for full membership.

It is also an advantage to the Student, since, at a very low figure often insufficient to pay the necessary charges, he is admitted to practically all the privileges of full membership.

In addition, as here in Liverpool, special branches are formed for Students, often under their own general direction, with the object of

accustoming them to the presentation and discussion of papers. It is evident that there is a need for such an activity and that it fulfils a want which is not provided in any other part of a Student's training. In saying this, I am of course aware that the Students of the Faculty of Engineering, at the University of Liverpool, have an Engineering Society of their own—but I still think the possession by an Institution of a Student branch is both essential and desirable.

The function of a Students' Engineering Society appears to be:—To accustom its members to present their technical knowledge to the public and to the profession, either in written or spoken language.

I do not know that this particular definition is sufficiently comprehensive in itself, as a mere association of persons and of different mentalities is of great help in more than one direction. Two heads are often said to be better than one, without making any odious comparison as to relative brain values. It is certainly true that a discussion with another person does enormously stimulate the production of ideas, and the different point of view of another individual often removes an apparently insuperable difficulty, or at best provides a more acceptable solution.

The other aspect of this question of association may be epitomised in the maxim that no one knows a subject thoroughly until he has had to teach, and, in opposition to that, it is often said that a teacher is born and not made, so you can take it whichever way you please.

I am convinced however, from my own personal experience, that I learnt very much during the few years in which it fell to my lot to be associated with the work of the Royal Naval College and the University of Liverpool, and, if I had my own way, I should certainly establish a system whereby employers made it a practice to send their best young men, at their own expense, to act as assistant lecturers at Universities for two or three years, if the Universities would have them. In this way I am sure that good men would be made more suitable for the higher positions in the profession, since the mere fact of having to put one's ideas in a form which can appeal to others is a great education in itself.

In this particular sense therefore, the discussion and reading of a paper by a young member of the profession needs not only an appreciation and understanding of one particular form of mentality, but also of the necessity of efficient presentation to meet the particularities of many minds and different points of view.

Whereas it should be easy for any trained engineer to formulate a technical solution to a problem, yet that is only the beginning of his

work, since, if progress has to be made, conviction has to be conveyed, not only to the profession, but to the general public. And it must not be forgotten that it is much better for one's personal comfort to be 20 years behind the times than one year in front. It is not difficult to overtake, but it is difficult to push forward against the inertia and vested interests of the public.

Yet it has to be admitted that many fully qualified engineers are distinctly lacking in comparison with men of much less education in the presentation of their opinion in writing and in speech. There is one reason for this—there are probably many—but one of the maxims for public speaking perhaps puts the case fairly well—"Have something to say"—this the engineer has; "Know how to say it"—this he often lacks; "Know when to sit down"—this is part of the art of knowing how to speak.

The effect of the war, resulting in high costs of production and living and heavy taxation requires that more people must work, and people who have worked must work harder. The war is not over with the cessation of hostilities and the prosperity of the community must depend on its efforts to acquire wealth by labour. The high costs of labour, which every thinking man will agree is likely to remain, in order that the conditions of living of the individual worker may be improved, will involve a greater application of power to industry.

Again, whereas in the pre-war days, money was gained too easily, it will, in future, be necessary more and more to abolish waste. It will not be sufficient to extract the juice from the meat, it will be necessary to utilise every particle of the substance so that the ultimate by-product may be as small as possible and of as high a value as practicable. Such work calls for intelligence, knowledge and application of a high order, coupled with an appreciation of commercial values far beyond previous requirements.

It is perhaps a singular fact that the early stages of scientific training proceed from the static to the dynamic state, and from the particular to the general case. This, in itself, is a distinct drawback to the student, for were it possible to reverse the process and begin our education from the dynamical side, the acquisition of knowledge would be rendered much easier. For example, I suppose the triangle of forces was nearly as great a worry to many of you in its initial appearance and nearly as difficult as the Pons Asinorum to the average schoolboy. Yet if a triangle be considered, it can be seen that the displacement from A to C is the resultant of the displacements from A to B and from B to C. Now if the displacements be divided by

the same period of time, the triangle of velocities is obtained, and if the triangle of velocities be again divided throughout by an equal time interval, the triangle of accelerations is produced which becomes the triangle of forces when the mass term is introduced. These and many other considerations show the need of thinking dynamically and the application of power to industry is more and more departing from the reciprocating or static idea of thought, entailing a greater demand on the intelligence of the professional engineer.

Such illustrations as these, which could be multiplied indefinitely, indicate that the present world has need of high intelligence, and that whereas the latter part of the last century was marked by the struggle of labour for recognition, the present one will witness a demand for increased reward for brains and knowledge.

Man is making an attempt now to displace the argument by force by an appeal to reason. The war has shown the wanton waste incidental to a failure to play the game and that the lesson is being learnt is evident from the constant striving for a better means of adjusting the balance between the rewards of labour and the return of capital. The more the reasoned argument comes into use, the greater the need for the trained intelligence, and the more important is it for the professional man to be able to convey to others the result of his knowledge and experience.

"He must know how to say it!" and, in so doing, must remember that many of the people to whom he desires to appeal have not the time, nor perhaps the inclination, to examine carefully a reasoned argument. He must, therefore, present the case in the fewest possible words and in the most convincing language. Through his intelligence he must sift from the evidence available the dominant fact—every problem can be reduced to practically one governing factor—and when this has been determined, the other aspects can be made to fall into line, radiating from it rather as a matter of detail. Having obtained, what may be called, the "strategic aim," he is then in a position to state the view-point in a manner that can best appeal to his audience and the production of the stage setting, or the atmosphere of his communication, is an important adjunct to success.

And here again he must be careful to avoid the particular, and those who have carried their studies to the stage where knowledge is a question mark are the least likely to make this error. There is not, in general, any one solution to a difficulty—granted there is one main solution, but it, in itself, is generally so imperfect that it needs further remedies to correct its errors. He should write down the general

equation of the problem and, from his knowledge of the properties of matter, eliminate those quantities which are not essential for practical application. Thus, for example, if the study of the motion of fluids be desired, the general equation must contain terms involving pressure, velocity, compressibility, viscosity and temperature at least, but by assuming the use of water, regarded as non-viscous and incompressible, and taking the temperature effect as constant, the problem is reduced to fairly simple treatment, and a solution, involving the main phenomena of fluid motion, is obtainable.

Although I have said that it is necessary to find the dominant factor, it is very often not nearly as simple as it looks, and if this dominant factor be not ascertained, then the solution has to be compromised on a balance of personal opinion with sometimes unsatisfactory results. If all other methods fail, there generally remain two which will give a fair indication of the nature of the problem, and I would describe these as—(1) the equation of energy or work, and (2) the calculation of probabilities. I have already referred to the benefit that may arise from taking the dynamic point of view as opposed to the static, and this extension to the equation of energy is but a logical step.

I may perhaps better illustrate these points by reference to a particularly important case which arose during the war and in which I was told that, as the matter was one of personal opinion, I had better agree on a compromise solution. I replied that in my opinion the matter was not one of opinion, but rather of arithmetic, if one could only find a basis for calculation.

I thought of these two ultimate methods and by applying them was able to reduce considerably the value of personal opinion.

The case in question arose from the enormous number of merchant vessels sunk by German submarines, when at a certain stage of the war it was fairly evident that if the same rate of destruction continued, it would not be possible for the Allies to continue their efforts.

The point was therefore raised that merchant ships should be provided with additional subdivision, based upon the idea that the more water-tight compartments there were in a vessel, the less chance there would be of sinking. This principle was perfectly correct so far as it went, but at the same time it was necessary to remember that goods had to be carried and that the number of ships available for carrying goods were being destroyed at a greater rate than they were being replaced. It was also evident that any protection would have to be paid by a sacrifice of carrying capacity, and the question was there-

fore one of calculating what sacrifice could be made without unduly affecting what might be termed the power of transportation of the available ships.

In the first place, it was only possible to protect the ship by bulkheads placed transversely, and if these were too close together longitudinally, it would not be possible to carry goods other than in relatively small packages. Further, since the damage caused by the torpedo was some 40 feet in length, it was fairly obvious that there was a considerable chance of carrying away more than one bulkhead. Approximate estimates were made of the loss of carrying power involved in two or three methods of protection, of which the simplest provided that the vessel should float with any one bulkhead carried away, in which case the estimated loss of carrying power was approximately 20 per cent. measured in deadweight.

It was further assumed, for purposes of comparison, that the protected ship was not likely to be sunk at all, but that she was just as liable to be hit and that she would take some four months to repair and replace in commission. For the unprotected vessel a rate of total loss was assumed of 30 per cent. per annum of the total number of vessels employed, while in addition to this, there was taken to be a rate of damage without total loss of 5 per cent. per annum.

On these assumptions an estimate was made of the total goods brought into the country in a given time, i.e., the energy equation was applied, and it was found that since these protected vessels had to be built and that there were practically none in existence, it would take somewhere about 10 months before the first of these vessels came into operation, and that the total quantity of goods brought into the United Kingdom in the unprotected vessels would have exceeded that carried by the protected ship until some further 18 months or 2 years had elapsed. In other words, to start a new programme on such a basis would not have been of benefit to the country unless the war had lasted at least 3 years from the date of commencement of the programme and that in the interval, owing to the greater labour involved in the construction of the protected vessels, the Allies would have been shorter of supplies than under the existing conditions.

The next phase of the problem was to determine what degree of protection could be given, in other words, what should be the spacing of the transverse bulkheads which were the means by which protection was afforded, and it was here that the calculation of probabilities was useful.

It has already been shown that it was not profitable to make a ship

unsinkable with any one bulkhead destroyed, and therefore it became necessary to consider whether the bulkheads should be a greater distance apart than the average length of torpedo damage, plus a small margin, say a total length of 45 feet. Now it was fairly obvious that unless a torpedo happened to strike the exact centre of a compartment, one bulkhead at least would be destroyed, with consequent loss of the ship, and it would appear from this argument that the farther apart the bulkheads were, the less was the chance of a bulkhead being carried away. It is fairly clear therefore that the spacing of a bulkhead should only be limited by the fact that a vessel should be able to float with any one compartment open to the sea, proper margin being given in making the calculations for a variation in the nature of the cargo carried.

In the Standard ships built during the war, this scheme of subdivision was adopted, but personal opinion was still in favour of placing the bulkheads much closer than this, as it was believed that thereby greater protection was obtained. As a matter of calculation an approximate formula was developed which indicated the chance of a bulkhead being carried away, which showed, what was not to be expected, that between the condition where the vessel could float with one compartment open to the sea, the chances of loss constantly increased right up to the stage where the subdivision was such that the vessel could float with any one bulkhead destroyed.

As those concerned in the transportation of supplies were naturally anxious to obtain as great a length of hold as possible, it was fairly obvious that the best solution to be obtained from all points of view was that in which the vessel could float with any one hold in communication with the sea.

I think this illustration of what was a very difficult and complicated problem indicates at least one more or less successful method by which it is possible to determine the prime factor of the problem, which in this case resolved itself into a calculation of the chance of a bulkhead being destroyed.

And he must know when to sit down. Some writers have an annoying habit of working up to a climax and ending there without further elaboration of what may perhaps be fairly obvious. This is, of course, the artistic and true ending of the story, and although it may be disconcerting, it is more than probable that the point is more emphatically made and remains more firmly in the mind than were the conclusion long drawn out.

Any anti-climax is dangerous—it is necessary to make the point—

it is dangerous to labour the moral, and further, any anti-climax to be successful must appeal rather to the heart rather than to the head. Make the point by reason—drive it home with sentiment—at any rate know when to sit down.

All these remarks lead up to the importance of the man himself as distinct from his technical equipment, and further show how necessary, for his world work, is a knowledge of human nature, both of which qualities may be termed “personality” in contrast to “technicality.”

The importance of personality to the engineer is becoming more and more recognised and, on its cultivation, will depend the advancement and reward of the profession. I remember on more than one occasion telling my honours students that I had done all I could to perfect their special knowledge, but the greatest factor in the problem was themselves, and what I had given them was only one-half of their total equipment for success in the world.

In my present work I have found, more and more the necessity for paying much greater attention than is customary to the value of the man himself, and, for comparative purposes, I estimate that personality is of equal value to knowledge, the man is as important as his professional equipment.

And that these matters are beginning to be recognised by others, I may draw attention to the conditions regarding personality and knowledge of language, which the Committee of Lloyd's Register has attached to the 14 scholarships which they give annually for students of Naval Architecture and Marine Engineering.

The examination subjects require a knowledge of English literature and composition, as well as of one other language, and, in the award of the scholarships, preference is desired to be given to Students who have a good knowledge of English and the selected language, so that here is a distinct attempt made to encourage those candidates who at least have the groundwork necessary to enable them to express their views in fit and proper language.

As regards personality, the regulation runs that candidates shall appear before a Board who will determine the relative fitness of the candidates to hold the scholarship, and the suggestion for the constitution of the Board indicates that the relative fitness will be governed to an appreciable extent by the personality of the candidate. The general constitution of the Board consists of the Academic Head of the University which the Student proposes to enter; the Professor of Naval Architecture or Marine Engineering in that University; a

nominee of the Faculty concerned who should preferably not be a member of the Faculty, and a nominee of Lloyd's Register of Shipping. This regulation, as you will see, is very broadly framed.

It will, perhaps, also be of interest if I refer here to some attempts which I have made to form some comparison between the total values of professional men, at a time when I had to examine a large number of candidates for special appointments. In general, the results were fairly successful, and I give them in order that my younger colleagues may have some idea of the various points of personality to which importance was attached.

When the candidates were interviewed, a sheet was prepared giving twelve columns divided into two groups—the first group was labelled “personality” and comprised :—

(1) *Appearance*.—Which was intended to take account of the first impression which the candidate created when he came into the room.

(2) *Speech*.—That is, the manner and decision with which he spoke in reply to questions.

(3) *Power of Expression*.—Which was indicated by the manner in which the replies to the questions asked were given, that is to say, whether they were terse, effective and informative.

(4) *Receptivity of Ideas*.—Which was gauged by the approximate time taken to grasp a question and to formulate a reply.

(5) *Character*.—Which was largely a matter of personal judgment, but was, to some extent, indicated by general mentality, and

(6) *Sense of Responsibility*.—Which was roughly assessed by the idea which the candidate possessed of the importance to be given to his decisions or replies to questions.

The second group which was termed “technicality” comprised the following divisions :—

(1) *Apprenticeship*.—The nature and extent of the experience in a works.

(2) *Education*.—Both before, during, and subsequent to apprenticeship.

(3) *Languages*.—Whether, during the course of education, the candidate had any particular knowledge of languages, both as regards English and another language, for which increased credit was given.

(4) *Responsibility*.—Whether during any portion of his career, the candidate had exercised any responsibilities and with what success.

(5) *Experience* gained by the candidate having due regard to his age, and

(6) *Experience* gained irrespective of the question of age.

Each of these twelve divisions were given equal numerical value, and the marking for highest proficiency in each group was indicated by the figure 1. Anything below this was taken as 1 +, 2 or 2 +, as the case might be, and the candidate with the least number of marks was the most satisfactory.

It should have been observed that most of these candidates had already been selected for proficiency on their paper qualifications and that the average age was somewhere about 30.

Out of a particular batch of 21 candidates, the highest total marks for personality and technicality were 13+ which was achieved by two of the candidates, as against a possible minimum of 12, while the mean value obtained for both personality and technicality was somewhere about 8, and the mean value of the total sum of technicality plus personality marks was slightly less than 16. This analysis differentiated fairly carefully between candidates, and subsequent experience justified the selection of candidates based on this method of assessing those qualities which it is desirable the engineer should possess in order to succeed in his profession.

Notwithstanding all the wise maxims and morals that I have quoted in the course of my remarks, I am in danger of breaking the rules myself. I have made my point of personality and am now flogging the moral.

And yet I must do it by an appeal to sentiment. It has been said that the war was won by the engineers—that may or may not be—but this much is certain, that they did their bit and that if they still continue to do the same, there is a great chance that we may yet win the peace. We must always remember, however, that no one solution ever achieved anything, no one remedy mastered the submarine menace, but it was rather the co-ordinated effort of all players which allowed the team finally to walk over.

And in this Student Society, you have to learn and to feel that your one contribution is not made for your own sake alone, that your especial gift of knowledge is only held by you on trust, and that the game itself is of much more importance to the progress of the human family than you are—a small, although useful, unit.

3rd February, 1921.

PROFESSOR T. B. ABELL, O.B.E., M. Eng. (*L'pool*), M. Inst. N.A.,
R.C.N.C. Ret., in the Chair.

"Oil Fuel Equipment for Locomotives."

BY F. ONIONS.

It is not the intention in this paper to delve deeply into the theoretical aspects of the use of oil fuel for steam-raising, but to give more attention to the practical details and making the necessary references to the theory to enable one to understand clearly the subject under discussion.

The author has rendered the paper as practical as possible, describing several systems selected, as being typical of the large number on the market, for the majority of the systems in use differ only in the type of burner, position of the burners and the steam connections to the boiler.

The question that faces the engineer at the present time is not the efficient use of the fuel, but the supply. During the past few years the number of vehicles using liquid fuel, such as the lighter petrols and kerosenes, has increased enormously, and this has tended to decrease the supply of the heavier residual oils used for steam raising.

Petroleum is a mixture of a series of oils which conform to the chemical formula $C_n H_{2n+2}$ beginning with $C_2 H_6$ down to $C_{15} H_{32}$. The average composition is taken as $C_{12} H_{26}$ for calculations.

The oil usually sold as fuel oil is a mixture of the more viscous petroleums of the order $C_9 H_{20}$ to $C_{15} H_{32}$.

The development of the uses of petrol has enabled the fuel oil to be used more extensively. Owing to the increased temperature of vaporization it has become much safer for transport and storage. In the countries where transport of oil is not difficult, this has made its use a commercial possibility. Crude petroleum is found in North and South America, South-East Europe, Borneo, Java and Trinidad. From Roumania is obtained a fuel oil of a higher calorific value than any yet discovered.

One of the earliest applications of fuel oil for steam raising purposes was on locomotives. This was quite natural, as the railway engineers in the vicinity of the oil fields could avail themselves of such cheap and abundant fuel. Its use in this way tended to keep back the scientific development in other parts of the world, owing to those engineers, having unlimited supplies of fuel at a nominal cost, using very crude and primitive appliances. The perfection to which the equipment has now been brought is due in a large measure to the experiments carried out in those countries to which oil has to be imported. Such is the case in England, where the cost of oil fuel is very high in comparison with coal. In other countries where coal, oil and all classes of fuel have to be imported, the necessity of obtaining the most efficient apparatus and of obtaining the best possible results from the calorific power of the oil is most apparent.

The railways using oil as a fuel on their locomotives are the Southern Pacific and Pacific lines in U.S.A., Austrian State Railways, Roumanian State Railway, Paris, Lyon and Mediterranean and Western Railways of France, and practically the whole of the South American Railways.

In England, the Great Eastern Railway have locomotives burning oil fuel, while on the London & North Western Railway experiments are being carried out with oil fuel on three types of locomotives.

The class of oil used on the respective railways varies considerably in composition viscosity, flash point, percentage of sulphur and water according as to whether the oil used is a crude oil or a bye-product of distillation.

Crude oil, by which is meant the natural product as found in the wells, differs from that sold as fuel oil, the process known as "topping" or first distillation being applied to remove the lighter petrols and kerosenes for the higher market value they possess. Crude oil is lighter in viscosity and has a low flash point, while "fuel oil" is a heavy viscous and dark-coloured oil. Other hydrocarbons, such as coal tar, creosote, blast furnace oil, water gas tar and other residua are also used under this head for steam raising.

From the engineer's standpoint it will suffice to consider only those oils sold commercially as fuel oils, and the aspects which govern their steam raising qualities. The engineer's chief concern after the question of supply is to obtain the highest evaporative results from a given calorific value, and thus the composition and specification of the oil are the first consideration.

The composition of fuel oils is given in Table I. The greatest

variation in the composition is in the amount of sulphur present, the amounts of carbon and hydrogen being practically constant.

TABLE I.
COMPOSITION AND CALORIFIC VALUES OF FUEL OILS.

	Carbon Per Cent.	Hydrogen Per Cent.	Sulphur Per Cent.	Calorific Value
Mexican ...	83.5	11.7	3.3	18,900 B.Th. U. per lb.
Russian ...	84.9	13.96	1.33	18,611 " "
Burman ...	86.4	12.1	0.5	18,864 " "
Galician ...	85.3	12.6	0.1	18,009 " "
Roumanian	87.11	11.87	0.16	19,320 " "
Californian ...	84.43	10.99	0.59	18,886 " "

Where there is a large amount of sulphur present in the oil, care has to be exercised in the use of the oil, owing to the corrosive effects of the sulphurous acids produced.

Calorific values of various oils are given in Table I, which shows that there is very little variation in the calorific value, a fair average been taken in calculations as 18,800 B.Th.U. lb.

Coal has a calorific value of 9,000 to 14,000 B.Th.U. lb., and hence the heating value of 1 lb. of oil is 30 to 100 per cent. greater than 1 lb. coal. In the case of coal, more heat is lost or absorbed in breaking up chemical combinations during combustion than is the case with oil, and also as much as 5 per cent. ash may be obtained. Thus a comparison on a heat basis is not conclusive, the real ratio being more nearly 2 to 1. The thermal efficiencies obtained with oil fuel are about 80 per cent. whilst with coal firing 65 per cent. efficiency is more common—an advantage in favour of oil over and above its higher calorific value, arising out of more perfect combustion, less excess air factor and greater heating surface exposed to flame.

The economical aspect depends very largely on factors outside test conditions, such as losses from banked fires, inferior stoking, dirty heating surfaces, &c., which arise in coal stoking.

The flash point of fuel oil has to be considered in connection with storage. For fuel oils the flash point varies from 80 degrees Fahr. to 300 degrees Fahr. The British Navy specification is for a minimum of 270 degrees Fahr., the Russian Navy specifies 212 degrees Fahr., and the American Navy 200 degrees Fahr. as the flash point.

This question of flash point is most important as regards danger from ignition during transport or storage, and does not affect the engineer in any other way. Provided with ample ventilation there is no great objection to oils having a low flash point.

General advantages of liquid fuel for locomotive work :—

(1) Reduction in weight of fuel to be carried. On some railways this shows a saving of 30 per cent.

(2) Reduced cost of handling.

(3) Less manual labour in stoking.

(4) No smoke, ash or clinkers.

(5) Adjustment of fuel to load—this can be done instantaneously by valve operation only. With coal firing it is necessary to have a thick bed of coal on the bars, and this is wasted when the engine has finished duty.

(6) Cleanliness in passenger service.

(7) Higher evaporative efficiency.

(8) Elimination of sparks due to fires, &c.

(9) Rapidity in steam raising.

(10) Large saving in shed economies. No cost for firewood, no fires to be raked out, no smoke boxes and tubes to be cleaned, no coal to be stacked or weighed, no firebars, rakes, shovels and other coal implements needed.

These are only a few of the points which could be raised in favour of oil fuel, many others no doubt could be found.

Before passing to the description of actual burners and equipment, a short explanation of the principles of combustion with reference to oil fuel will be given.

The principles involved in the use of oil fuel are practically identical with those of coal firing, but in the case of oil, the difficulty of arriving at and maintaining complete combustion is much greater. Stated briefly, it is necessary to break up the fuel into pieces of such size that the oxygen in the air will unite perfectly with them in combustion. Any deficiency in this respect results in some portion of the fuel passing away as unburnt hydrocarbons and some portions left behind as coke. It is necessary that only the exact amount of air necessary for complete combustion be admitted to the furnace. Any excess of air produces different chemical changes in the gases, having the effect of lowering the temperature in the combustion chamber, and thus lowering the efficiency.

In Fig. 1, the section of a locomotive boiler illustrates the manner in which combustion takes place with coal fuel, and also the admission

of air at the fire-hole door necessary to burn the volatile gases given off from the burning coal. This illustrates to some extent the problem which arises in the case of oil fuel, as it is not possible to spread the fuel oil on the firebars, or to break it up into lumps; recourse has had to be made to atomize the fuel and to distribute the oil over a wide area, so as to represent the laying of the coal on the bars. The principles of air admission are practically identical, i.e., it ought to follow the direction of combustion. All the air should be admitted behind the oil jet, and the oil spray should so completely cover the area of the firebox that no excess of air can pass through. In practice, perfect combustion is very difficult to attain, for with oil, as well as coal, some heat is lost in the breaking up of the constituents

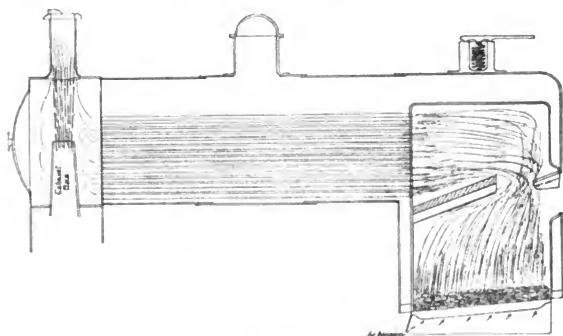


FIG. 1.

Combustion Diagram for Coal-Fired Loco. Boiler.

represented in the molecular heat of formation of the substances. By perfect combustion is meant not only complete combustion, but combustion with the largest per cent. of CO_2 in the flue gases. It is important that the unburnt gases should not come into contact with the cooler tubes and plates until combustion is complete, to avoid condensation of the unburnt fuel. This is effected by the building of brick combustion chambers, the bricks quickly rising to the temperature of the burning fuel, act regeneratively by maintaining the furnace temperature. The brick arch prevents gases rising vertically and passing away unconsumed through the smoke tubes. The last consideration in the construction of the oil-burning furnace is that of space, which should be proportioned in accordance with

the quantity of fuel to be burnt, and the quantity of air required. Unfortunately, in locomotive practice, the oil required is such a varying factor that some compromise has to be made between maximum and minimum duty. The form and area of the brickwork are also important.

The essential in the burning of the fuel oil effectively, is the complete atomization or breaking up of the oil into minute particles. The word "mist" conveys a more definite idea of this. These minute particles must also be spread out as much as possible, so as to ensure a complete mixture with the incoming air, so that the amount of oxygen necessary for complete combustion of each particle is present.

This is analogous to the breaking up of the coal on the firebars, rendering it full of minute interstices and presenting as large an area as possible to the incoming air. The disintegration of coal takes place in a state of incandescence within the furnace, but oil has to be supplied continuously as it is burnt, because with the heat of combustion it becomes immediately vaporized, and does not remain incandescent. Regulation of heat to the boiler is thus dependent on the quantity of oil supplied.

The theoretical quantity of air required for 1 lb. of oil under conditions of perfect atomization and admixture is 15 lb., but considerably more than this, about 24 lb., is taken as the basis of calculations.

The three methods in use for supplying and pulverizing the oil are :—

- (1) Steam jet method.
- (2) Air jet system.
- (3) Pressure jet system.

Each system breaks up the oil more or less effectively, and in this respect there is little to choose between them. The cost of doing so is quite different in the three systems, and this is the main aspect to be considered in each case. Thus complete atomization although absolutely essential is not the only factor of successful fuel combustion, nor is it the most important.

The temperature of the oil, furnace temperature and air temperature have an important bearing on the degree of combustion of each particle. The temperature of the oil passing through the burner controls the fineness of atomization. The object of heating is to break down the viscosity of the oil, and so render the spray finer. The temperature of such heating depends on the viscosity and the flash point of the oil. If the temperature is too high, it results in vaporization, and in some cases "cracking" or breaking up of the chemical constituents of the

oil. The effect of temperature on the oil will be noted from the following figures:—

Water has a viscosity of 25.5 secs. at 60 degrees Fahr.

Fuel Oil " 1,285 " 60 " "

" " " 25.5 " 150 " "

The Steam Jet System.—This was the earliest form of apparatus for burning petroleum. Steam was and is used for breaking down the viscosity of the oil and atomizing it as it leaves the jet or burner. It thus serves a double purpose, as the viscosity can only be broken down by preheating and atomization rendered possible.

The simplest form of steam jet burner is that of a double concentric tube 18 inches to 2 feet long. Steam passes between the inner and outer tubes and the oil supplies through the inner tube at the same end. At the discharge end the inner tube is closed, and a number of holes drilled in a ring round the circumference about 2 inches from the end. The oil thus mingles with the steam and both are discharged together in the form of a spray. Such a method is not only wasteful of steam, but also of oil, as the atomization could not be carried out to the necessary degree of fineness.

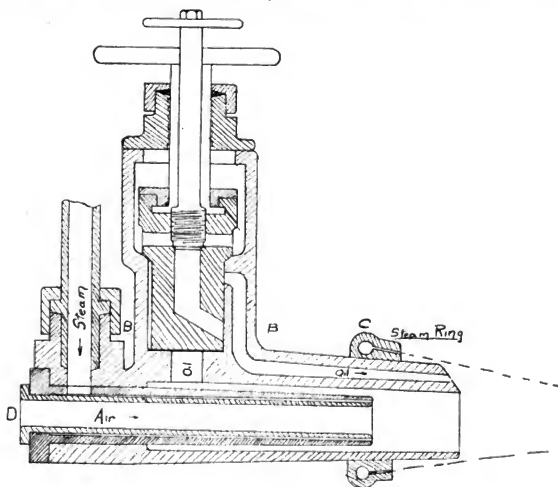


FIG. 2.

Holden Burner.

Modern steam jet burners are designed to work more economically, i.e., to give the highest degree of atomization with a minimum quantity of steam. The apparatus necessary with the steam jet consists of the oil tank on the tender, together with the necessary valves supply pipes, and steam connection between boilers and burner. The burner is self-contained, and is all that is necessary for the regulation of oil and steam. The oil is heated in the oil tank by means of a steam coil and flows by gravity.

The "Holden" System.—Designed by Mr. Holden, Chief Engineer of the G. E. Railway, in 1887, and still used on the railway in England and on the Roumanian State Railway. The burner is shown in Fig. 2. It consists of a coned body *AA*, to the interior of which oil is supplied through the valve *BB* inside the body. An annular steam jet is introduced possessing a central passage for assisting in the supply of air, and also to enable a wire to be passed through the burner without shutting off the oil or steam. At the front of the burner immediately behind the nozzle is fixed a steam ring *C*, to which steam is admitted and allowed to escape through six fine jet holes. It is this jet which enables the burner to dispense with the brick walls necessary with other devices. Another requirement fulfilled by this steam ring is that the jets induce a strong current of air which is carried forward and mixed with the spray as it emerges from the nozzle. The steam supplied to the ring is conveyed from a small regulating valve attached to the rear end of the burner, so that only one steam pipe is required from the boiler. The angles of the fine jets are such as have been found most thoroughly to atomize the oil.

The valve *BB* used for regulating the oil supply is of such construction that a small reservoir of oil is formed in the body of the valve and with the small valve in the larger body allows of very fine adjustments in the flow of oil.

This system was devised so that little alteration was necessary in the firebox, enabling the locomotives to be converted at once from oil burning to coal burning, and vice versa, without any structural alterations being made in the firebox. On these locomotives steam is first raised by a wood and coal fire in the ordinary way, and when 30 to 40 lb. pressure of steam was attained the fire was levelled over and the burners started by opening the steam supply to the central cones of the burners and admitting oil through the regulating valve.

The burners are placed just above the level of the fire, so that any minute explosions due to trapping of some unburnt fuel under the brick arch are eliminated. Only two locomotives are running at

present fitted with this system in England, owing to the high cost of fuel. These are burning the residue from the Company's oil gas plant at Stratford.

Wallsend Steam Jet System.—The Wallsend system constructed by the Wallsend Engineering and Slipway Co., Ltd., is a departure from the systems using a flat type of burner. Experience has shown that to obtain the highest efficiency from an oil-fired locomotive it is necessary to obtain a very high temperature in the firebox to ensure the complete combustion of the heavy residuum now used as fuel oil. The effect of incoming air, both as regards cooling and distortion of the flame, has been carefully considered and provision made for the utilization of the heat radiation from the brickwork to assist in the combustion of the fuel. The Wallsend burner was designed to give a flame or spray in the form of a hollow cone, so that the oil is thrown along the sides and bottom of the furnace. In Fig. 3 is shown the furnace arrangement with the burner facing the tube plate. The fuel is thrown under the arch into an intensely hot zone into which no cold air enters, so that any unconsumed oil reaching this zone becomes immediately vaporized by the heat and becomes highly inflammable, and instantly consumed on meeting air at the point *A* when passing over the brick arch.

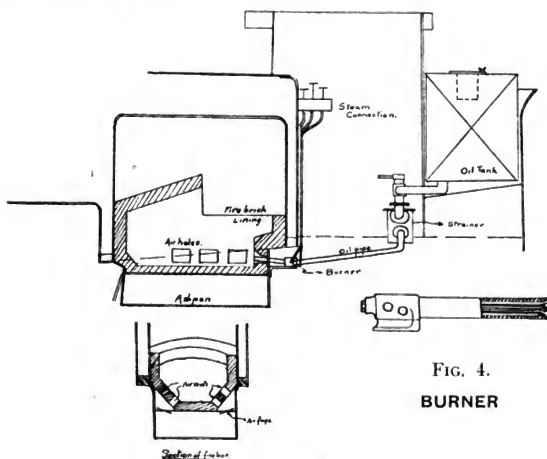


FIG. 4.
BURNER

FIG. 3.
Arrangement of Wallsend Steam Jet System.

The burners may be fitted under the tube plate, and although the same intensely hot zone cannot be obtained with the burner in this position it has proved highly satisfactory and has the advantage that the burner is visible from the firedoor, so that any obstruction in front of the burner is readily seen. Fig. 4 shows the burner and form of spray. The burner is provided with a steaming out connection for blowing through on shutting down. This is of great importance, as any oil left in the burner would carbonize, due to the intense heat radiated from the furnace.

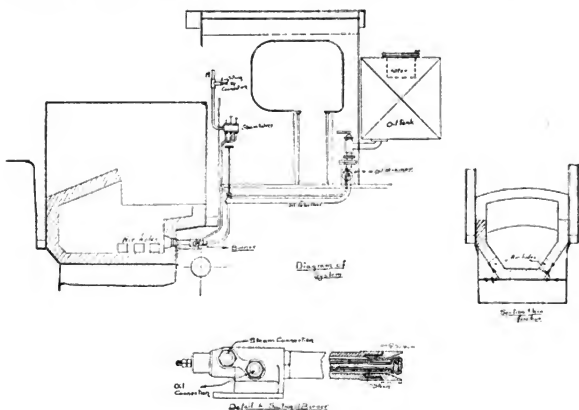


FIG. 4.

Wallsend Steam Jet System for Tank Locomotive.

Fig. 3 shows the general arrangement of an installation on a side tank engine. The oil tank is fitted with a heating coil in case the oil becomes too viscous to flow properly in cold weather. A filter is fitted between the oil heater and the burner, to prevent dust from getting into the regulating cock and the burner.

With this system, during four runs of 96 miles each, an average actual evaporation of 13 lb. of steam per lb. of oil was obtained.

Scarab Oil Burner and System.—This system, invented and fitted on locomotives in Mesopotamia during the war, is being tried by the L. & N. W. Railway Co. on three express locomotives. Precursor 4—4—0 type, George V 4—4—0, and Claughton class 4—6—0 four-cylinder simple.

Fig. 5 shows the arrangement of plant on the locomotive. The oil tank is carried on the tender placed transversely, from which the oil flows through a steam heater to the flexible pipes between engine and tender. Thence it flows through the oil valves to the three

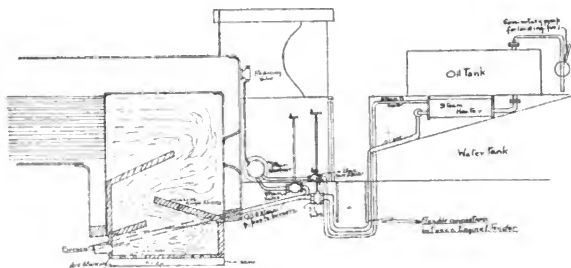


FIG. 5.

**Scarab System as fitted to
L. & N. W. Ry. Co.'s Locomotive "Watt."**

burners, two placed equidistant on each side of the centre line, and one of a large size in the centre. The main details of the burners will be seen in Fig. 6. The oil flows in at the upper connection, along the nozzle and down the "U" shaped tray. The oil flows over

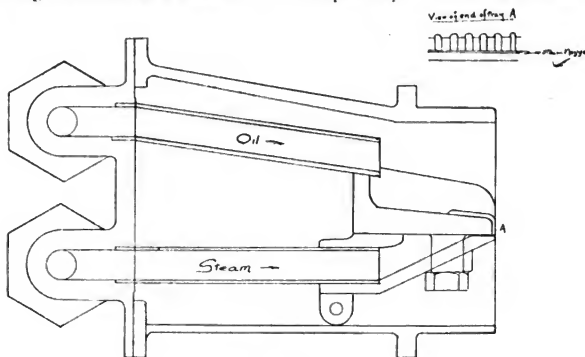


FIG. 6.

Scarab Burner.

the corrugated lip, which breaks up the oil into a number of small streams, from which it is blown by a jet of steam issuing from the flat nozzle. The nozzle is capable of being adjusted to give the most satisfactory results for each boiler. The jet of steam gives a flat fan-shaped spray which fills entirely the width of the firebox. The burner is mounted on a cast-iron cylinder fixed to a rectangular box in place of the usual ashpan. The burners are placed in front of the firebox, and the air is admitted at the front end through the duct between the floor and casing, and up through holes in the floor immediately in front of the burners. Three brick arches are built in the firebox, one immediately over the burners, springing from a point near the foundation ring. The second is built as a deflector under the firedoor, and the third as in a coal burning engine, but stopping off about 16 inches from the tube-plate. Brickwork is carried up the sides as high as the lower arch over the burners. This construction by lowering the floor increases the capacity of the box, and the duct under the floor forms a heating chamber for the air. The steam pressure to the burners is supplied from a reducing valve at a pressure of from 10 to 15 lb. through a receiver to the burners. Steam is initially raised by coupling up the steam connection to another engine and using the steam from this engine for the burners, until the pressure is about 15 lb., when the steam from the boiler is available. A connection is made for blowing out the pipes between the heater and the burners when the engine goes in the shed. When first fitted to the "Precursor" locomotive two burners were used, but were found unsatisfactory and a third was added, and has since been used alone with perfectly satisfactory results. With the third burner alone trains up to the rated capacity of the locomotive are being run quite satisfactorily. With this burner a consumption of 30 lb. to 33 lb. of oil per mile with a train load of 290 to 300 tons excluding engine and tender was obtained.

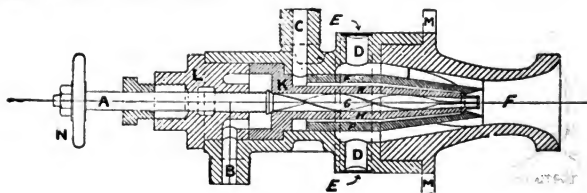


FIG. 7.

Kermode Steam Jet Burner.

The *Kermode Steam Jet Burner* is shown in Fig. 7. The references being as follows :—

- A*—Oil valve for regulating supply.
- B*—Oil admission.
- C*—Steam admission.
- D*—Openings for air admission.
- E*—Movable perforated strap.
- F*—Air cone containing spiral guides.
- G*—Oil valve spiral.
- H*—Hollow steam cone.
- K*—Base of cone *H*.
- M*—Spider for rotating cone *F*.

The steam passing through heats the oil in the inner cone *H* and both discharge at the needle valve at the back of the air cone *F*. The oil has a swirling motion imparted to it, in its passage through spiral *G*, and oil, steam and air are passed through the air cone *F* into the furnace. The flow of air is induced by the flow of steam, and its quantity is regulated by means of the perforated strap *E*. The steam in this burner performs the duties of oil heating, atomization and air induction, and it is claimed that the burner has a wider range of capacity than any other on the market.

Von Boden Ingle's Burner is shown in Fig. 8. The special feature of this burner is that the oil is atomized on the outside corrugated lip by the steam impinging on it. This does away with

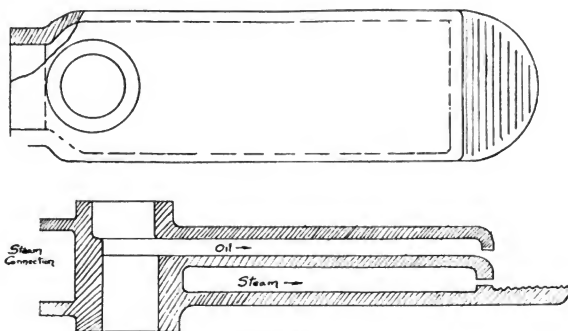


FIG. 8.

Von Boden Ingle's Burner.

waste and dripping of the oil and also permits of the cutting down of the fire to practically a candle flame, and leaving it so for any length of time. Another feature is the simplicity of construction. The burner is cast in one piece so there are no valves or delicate parts to get out of order. The oil connection to burner may be made either at the top or bottom to suit space or place.

Advantages of Steam Jet Systems claimed by makers:—

- (1) Simplicity of construction.
- (2) Involves no pumping apparatus.
- (3) Low initial cost ; the steam jet system may be fitted at a cost of about £80 to £100 exclusive of tanks and firebox alterations.
- (4) Occupies small space and will deliver up to 500 lb. oil per burner per hour.
- (5) Adaptable to any form of flame, flat, circular or conical.

Disadvantages:—

- (1) The steam reduces the temperature of the firebox which it is vital to maintain as high as possible.
- (2) It is incapable of rapid adjustment according to the varying demands of the locomotive.
- (3) It is affected by changes in steam pressure, and priming will put out the flame with the risk of explosion on relighting.
- (4) Steam forms deleterious compounds with the sulphur and attacks plates and tubes.

Some observers have stated that the steam will combine with the carbon in the oil and form CO and free H, which afterwards burn, thereby adding to the heating efficiency of the boiler, but this is a fallacy, for it takes approximately the same amount of heat to disassociate the O and H as is gained by their combustion.

Most of the steam jet systems are adaptable for use as air jets, but owing to the great lack of space on the locomotive it is not possible to put an air compressor together with receiver on the footplate. The *air jet system* is not yet used for locomotive purposes.

In the pressure jet system, the need for any external agency as steam or air for atomization is eliminated, it taking place under the pressure of the oil, as it is delivered at the burners. Heavy oils such as are used cannot, owing to their viscosity, be atomized at ordinary temperatures, and they have to be heated to such a temperature as will break down their viscosity, and this occurs at about 200 degrees to 300 degrees Fahr.

The atomizers used in this system have one common feature, the fineness of the holes in the nozzle through which the oil is forced. As these vary from 1 millimetre to 3 millimetres it is necessary to have filters or strainers through which the oil has to pass on the way to the burners. In order to raise the pressure of the oil which varies in different systems from 30 lb. to 150 lb. a steam pump is used. A diagrammatic arrangement of the system is shown in Fig. 9. The pumps found suitable for liquid fuel are of the double-acting type, made by Worthington, Weir, Tangye, &c., in universal use as boiler feed pumps. Owing to the viscosity of the oil and the necessity of maintaining a steady flow, an air vessel is fitted to the pump of about five times the capacity of the pump cylinder. In

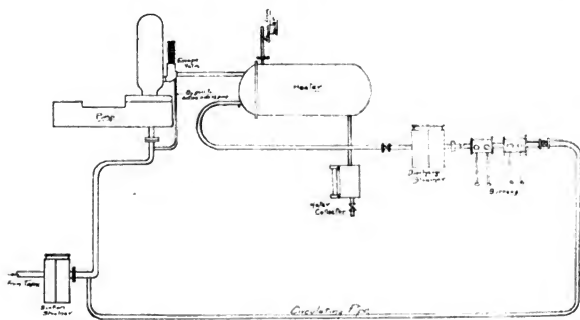


FIG. 9.

Diagrammatic Arrangement of Pressure Jet System.

selecting a pump for oil fuel not more than $\frac{1}{3}$ -th of the rated capacity as a boiler feed pump should be taken, and the pump run at not more than $\frac{1}{3}$ -th of the pump speed. For oil duty the pump should have valves with metal to metal seats and have a cast-iron liner in the pump barrel owing to the action of oil on rubber and brass. An automatic release valve should also be fitted with adjustment for various pressures. Any excess of pressure would thus flow back to the suction side of the pump. This allows any irregularity to become apparent at once to eye and ear. As force pumps are not adapted to suction, the oil should flow to them by gravity. The oil after leaving the pump is heated by steam from the boiler, the oil passing slowly through the heater and being heated to the temperature of 200 degrees to 250

degrees Fahr. These heaters should be made of solid drawn steel or rolled steel, as cast-iron is too porous for use with oil. The pressure of steam in the heaters should be nearly that of the boiler, so as to raise the temperature of the oil as high as possible.

The Wallsend Howden System manufactured by the Wallsend Engineering & Slipway Company, is used largely on the locomotives in America.

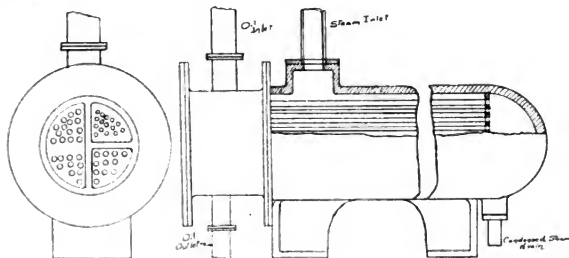


FIG. 10.

Wallsend Howden Heater. 3-Flow Steam.

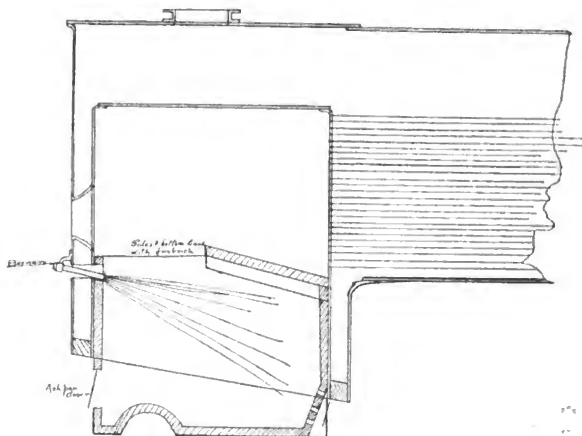


FIG. 11.

Wallsend Howden Firebox Arrangements.

The oil is delivered to the burners under high-pressure and at a temperature of 250 degrees to 350 degrees Fahr. Atomization is attained without use of any external agency. In order to reach the burners the oil passes from the pump through a heater of the type shown in Fig. 10, a strainer and distributing box fitted with steam valves to each burner valve so that when any burner is stopped steam can be blown through the pipe and burner, so clearing the burner of any oil remaining in it.

The firebox arrangement is as shown in Fig. 11, the general arrangement being similar to that shown in Fig. 9. A device for steam raising without recourse to wood or other fuel, and without the necessity of taking steam from any other source, is shown in Fig. 12.

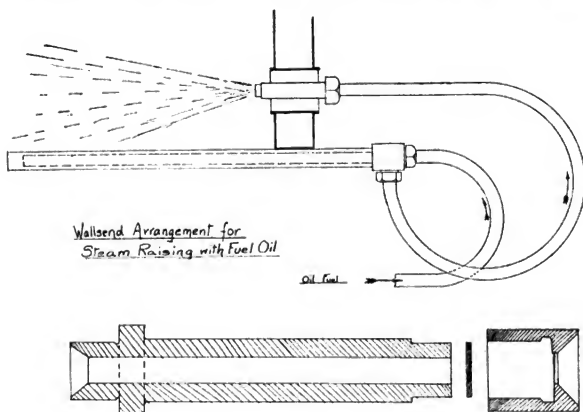


FIG. 12.

Wallsend Howden Burner.

The advantage of this is mainly on those railways where wood or coal is not available or on long stretches of line where no auxiliary steam is available. The apparatus consists of a double concentric tube through which the oil passes from a hand pump to the burner. The double concentric tube for heating the oil is introduced into the firebox a few inches below the burner and projects sufficiently to be within the flame from the burner. The initial heat is provided by a handful of oily waste ignited under the end of the heating tube, and after a few strokes with the hand pump the oil will light at the

burner and continue to heat automatically. The oil is forced into the furnace in the form of a conical spray, from the burner which is shown in Fig. 12. It consists of a plain tube, one end of which is screwed for connection to the supply pipe and to the other end is attached the nozzle. Between the body and the nozzle is placed a steel disc perforated by two or more holes drilled at an angle to give the oil a rotary motion as it passes through the diaphragm. It will be seen that with this burner it is not possible to regulate the amount of oil to the burners by means of the oil valves, and any regulation required being by cutting in or out one or more burners. This arrangement simplifies the question of air admission, as the quantity of oil passing through each burner can be determined. Steam being raised or available, the oil pump is started and steam admitted to the heater. In the course of a few minutes the temperature rises to about 250 degrees Fahr. at which the burners may be lighted.

The normal pressure of this system is 150 lb., but can be regulated to suit the demand for steam.

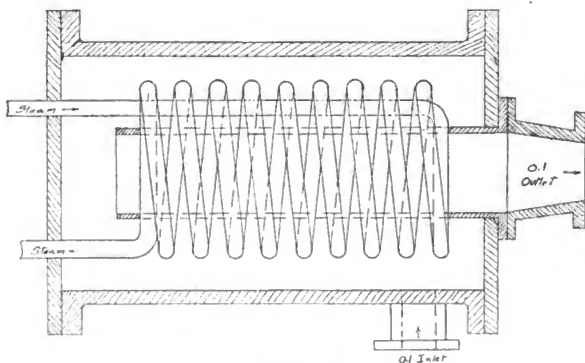


FIG. 13.

Meyer Smith Steam Heater.

Meyer Smith System is manufactured by Smith's Dock Company, North Shields. The main details follow the lines shown in the diagram in Fig. 9, but it is in the manufacturing processes, and details for which special claims are made. The heater is shown in Fig. 13 made of wrought iron with all the branches and flanges welded on, which

ensures a perfectly oil tight vessel. The steam tubes are made from solid drawn steel, and both ends from steel plates. The burner and distribution box are shown in Fig. 14, in which it is seen that the valve for each burner is situated opposite its respective burner. Another point claimed for this burner is that the burner can be taken in or out without the disconnecting of oil and steam pipes. The system only requires a pressure of 30 lb. to 70 lb. gauge, which simplifies the pump arrangements necessary.

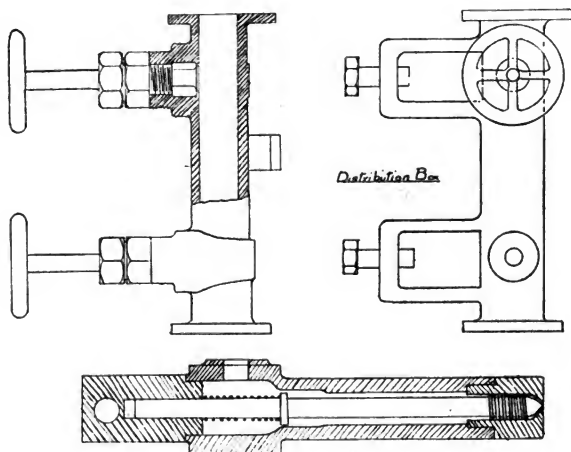


FIG. 14.

Meyer Smith Burner.

It does not generally follow, as would perhaps be apparent from the claims put forward by the makers of the various systems, that any of the systems can be used satisfactorily on locomotives owing to the constant variation of load and duty required from it.

The Advantages of Pressure Jet Systems :—

- (1) Oil is atomized at a temperature to its boiling point.
- (2) Spray is evenly distributed and flame is short.
- (3) The quantity of air can be regulated more nearly to theoretical requirements than with steam jets.

(4) Hot oil and hot air are introduced at a nominal consumption of power (about 1 per cent. of boiler capacity).

(5) Does not produce deleterious products of combustion.

(6) Perfectly silent operation.

Disadvantages :—

(1) Necessitates large number of auxiliary valves, pumps, pressure gauges, &c.

(2) Depends on pump for compression and atomization of oil.

(3) Initial cost is high, about £600, depending upon the type of locomotive.

The controlling factor which governs the type selected is not the supply of oil to the burner, which is a minor detail when compared with the factors which govern the complete combustion of the fuel. The factors the engineer considers in selecting the system are suitability under all conditions, such as when a locomotive is starting, running at top speed, &c. These factors together with the variation wind resistance, gradients, stopping and starting, make the problem of estimating an average, to base calculations upon for air supply, a difficult one. When coal is burnt on the locomotive the thickness of fire and size of coal determine largely the air supply for combustion, and if required air can be admitted above the fire to burn the volatile gases evolved from the coal, but in the case of oil fuel, the air supply must be admitted as nearly as possible with the spray from the burner, so that complete combustion can take place at once, and it is fatal to admit air to any other part of the furnace. By reference to the burners described it will be seen that with steam jet burners the flame can be given any form desired, but with the pressure jet, the jet is confined to the discharge from a round nozzle in order to accomplish satisfactory atomization, this is made more effective by giving the oil a spiral motion as it leaves the nozzle, either by means of a spiral or through holes in a diaphragm.

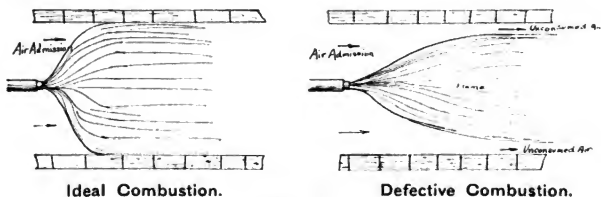


FIG. 15.

The first detail in the furnace construction is that the flame should fill entirely the combustion chamber space allotted for combustion, just as it is necessary for coal to lie evenly over the firebars, and that there should be no holes for cold air to pass through unconsumed. The ideal form of furnace for oil combustion is that of the Lancashire boiler. The diagram showing the ideal form is shown in Fig. 15, showing the oil jet of conical form entirely filling the area of the furnace tube. The second diagram shows the defective combustion air leaking past the flame without being consumed and thus passing on to cool the brickwork and the furnace tubes. The second essential is that the air should be admitted behind the jet, and the air pressure should be uniform round the jet, just as air is admitted below the firebars in coal burning, with an equal pressure at all points of the grate area.

In any application of oil burning to a locomotive, the two conditions just enumerated should be aimed at, and any claims which do not embody these conditions are not likely to be fulfilled. This is striking a new note with respect to oil burning locomotives, but it illustrates why the existing methods do not give results commensurate with those readily obtained on stationary boilers. The condition farthest removed from the ideal is when the oil is burnt in the open air. The oil burns with a white hot flame for a short distance, but before combustion is complete the air cools the hydrocarbons, and the unconsumed portion passes away as dense black smoke. This is what happens when the firebox door is opened or when cold air is admitted in any quantity. The second diagram in Fig. 14, illustrates what occurs in a locomotive firebox when the spray fails to fill the whole of the combustion space, and demonstrates the need for a high furnace temperature. It is with this object that brick linings are built in the fireboxes.

In the diagrams of the firebox arrangements of the various systems it will be noted that the combustion of oil fuel takes place under the brick arch within the brick lined space. This space is more or less irregular in shape, and this operates to the disadvantage of the use of oil fuel on locomotives as compared with land or marine installations. Tests carried out on a locomotive boiler show an evaporation of 11 lb. of steam (from and at 212 degrees Fahr.) per lb. of oil fuel, whilst on a Lancashire type 16 lb. of steam (from and at 212 degrees Fahr.) per lb. of fuel was obtained.

Mr. Gibbons, of the South American Railways, proposes that the brick arch and linings should form a cylindrical combustion chamber

as shown in Fig 16. The burners are placed at the front of the firebox, and arranged so that the flame entirely fills the cylinder, the necessary air being admitted to the chamber through the damper and up the passage *A*. This form of cylindrical combustion chamber is an attempt to bring the Lancashire type furnace into the locomotive firebox, and to avoid the right-angle corners and flat brickwork which allow unconsumed air to pass the flame.

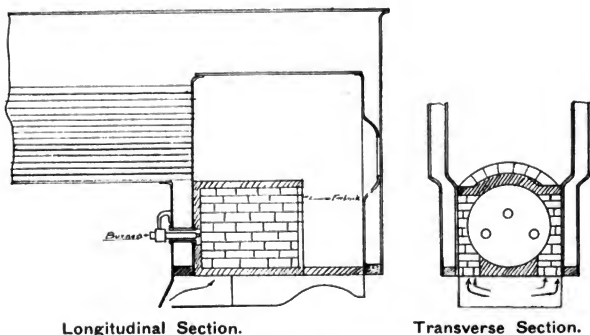


FIG. 16.

Gibbons' Arrangement.

Whilst in the majority of firebox adoptions to burn liquid fuel the knowledge and experience gained with successful coal burning have been utilised, the original methods of draught regulation have been retained with very unsatisfactory results. The original ash-pan damper has, with the exception of the Wallsend types, been retained unaltered in form or position. The method of operating these is by a simple lever connected with a rod to a hand-lever on the footplate. The rod has three or four notches engaging with a holding catch. The effect of opening such a damper is to expose a very considerable area for air admission, which is not very greatly altered by differences in the adjustment provided. Under the most intelligent operation by the fireman these fall short of effective regulation of air supply in the case of oil fuel. A step towards an ideal is in the butterfly valve type of damper adopted by the Wallsend fireboxes, which operates by means of a screw and hand wheel on the footplate. Anyone who has had experience with stationary boilers knows the accurate adjustments possible with the air distributors, and can compare with the locomotive arrangements.

The draught is dependent on the degree of vacuum in the firebox, and this is dependent on the discharge of exhaust steam into the chimney. Thus the velocity of air through the dampers will vary directly with the velocity of the exhaust steam in the exhaust nozzle. Within certain limits the rate of combustion is also dependent upon the exhaust steam effect. Experience has shown that $\frac{1}{3}$ -th of the degree of vacuum in the firebox is required for oil fuel compared with that for coal firing, as there is less resistance to flow than is the case where a thick bed of coal is kept on the firebox. On the other hand, oil requires about 24 lb. of air per lb. of fuel, while coal requires 18 lb. of air per lb., so that while the resistance to the passage of air is less, the quantity of air is greater, weight for weight.

The determining factor of this draught production is the diameter and position of the exhaust nozzle in the smokebox. With regard to the diameter of the nozzle, in locomotives having 16-inch diameter cylinders and upwards the exhaust nozzle is from $4\frac{1}{2}$ inches to 5 inches diameter. This diameter can be increased by 1 inch or more until it is determined experimentally that the blast nozzle gives the lowest vacuum commensurate with combustion.

The position of the nozzle in the smokebox is fixed by the condition in which equal gas flow in each tube is attained. This also has to be determined experimentally, owing to the varying conditions in locomotive boilers. It is a well known fact that two locomotives having the same type of boiler, in fact, of the same dimensions, have different steaming qualities. The best method of regulating the influx of air is by making the blast pipe so that the velocity of steam issuing can be adjusted to suit requirements. A variable exhaust nozzle so designed and under rapid control by the engineman, and used for rapid regulation of draught under all variation of load would give some larger efficiencies for the locomotive boiler. This should be used in conjunction with the damper capable of accurate adjustment.

Mr. Holden on his locomotive fitted a conical shaped cap on the blast pipe, which could be placed on or removed by a lever on the footplate to increase or decrease the velocity of efflux of the exhaust steam, and so had this exhaust steam effect somewhat under control.

The five main points which have to be considered in the conversion from coal firing to oil burning are :—

- (1) Main draught regulation by means of variable exhaust nozzle.
- (2) Auxiliary draught regulation by accurate damper adjustment.
- (3) As large a smokebox as possible to give full expansion of burnt gases.

(4) Enlargement of chimney to give double sectional area where possible.

(5) Blast pipe placed to give equal distribution in all tubes.

In the following tables are given some particulars of trials carried out with oil burning appliances on two railways, one in Mexico and one in England :—

Mexican Railway.—With Wallsend Howden Pressure Jet System of four Trips :—

Total weight behind engine	=	190 tons
Miles travelled	=	15.52 miles
Oil burnt during test... ..	=	600 lbs.
(Train) Ton miles per lb. of oil	=	5

With steam jet system (Holden's) on same type locomotive and same load—

Mileage	=	15.52
Oil burnt during test... ..	=	720 lbs.
(Train) Ton miles per lb. of oil	=	3.4

L. & N. W. Railway.—With “Scarab” Burners fitted to 4—4—0 Precursor Locomotive “Watt,” No. 2,585 :—

Weight of engine and tender (fully loaded) =	100 tons
Mileage (Euston to Rugby)	85 miles
Load behind engine	214 tons
Oil burnt on trip	2,885 lbs.
Ton miles per lb. of oil	6.25
(2) Mileage (Rugby to Liverpool)	85 miles
Load behind engine	230 tons
Oil burnt on trip	2,552 lbs.
Ton miles per lb. of oil	7.66

In connection with the L. & N. W. Railway trials a locomotive of the same type burns about 50 lb. of coal per mile, or with same train 3.75 ton miles per lb., or approximately an oil fired locomotive will give twice the work per lb. of fuel. Owing to the high cost of oil fuel it has become a commercial failure when compared with coal fuel.

Coal in this country is about £2 per ton, while oil costs £13 per ton at the English ports. Thus while the use of oil presents greater efficiencies, and saving in the cost of handling, storage, &c., the nett result is a heavy loss, but perhaps at some future date, if the oil supply holds out, and the cost comes down, the use of oil for steam raising on locomotives will become a commercial possibility.

The Paper was accompanied by numerous plans and diagrams, some of which have been reproduced as illustrations in the text.

Obituary.

THOMAS DOWNIE, who died on 11th November, 1919, was a native of Fifeshire. He served an apprenticeship of seven years with James Bertram & Son, Engineers, Leith, and then joined the Allan Line, remaining with them for a number of years. Subsequently he joined The Pacific Steam Navigation Co., and became Chief Engineer of their largest steamers, his last position being in the S.S. "Britannia." During the period when he was second engineer of one of these steamers, the propeller was so damaged when out on the West Coast of South America that it was quite impossible to steam, with the result that the steamer would have had to remain until a new propeller arrived out from England, close on a period of six months, but, owing to his skill and experience, a new propeller was made at one of the Chilian arsenal works under his immediate supervision and the steamer returned home within half the time it would have taken to have got the new propeller from England. He was promoted on his return, and also received monetary recognition from the Company and the Underwriters. He was afterwards appointed Lloyd's Surveyor in Glasgow, and then left Lloyd's in order to take up a position as manager of McChonies, Engineers, Glasgow, sugar refinery machinery specialists. He next joined Messrs. H. & C. Grayson as engineer manager, and remained with them for some years, when he left and started a repair works of his own in Caryl Street, Liverpool. After giving this up he practiced as a consulting engineer and also as a specialist, working various patents of his own and acquiring the working of others.

He was elected a Member of the Liverpool Engineering Society on 13th November, 1895, and had presented valuable books to the library.

HENRY FORBES was born on the 24th July, 1864, in Forfarshire, Scotland, and served an engineering apprenticeship with Messrs. Alex. Shanks & Sons, Arbroath. At the age of 21 years, he joined The Union Steamship Company, Southampton, rising to Chief Engineer,

resigning from this concern in 1900 and taking the appointment of superintendent engineer for Messrs. Galindez Bros., London, managers of a Spanish Shipping Company. In 1903, he joined the service of The Royal Mail Steam Packet Company, as assistant Superintendent Engineer, and ten years later he was appointed Superintendent Engineer of The Pacific Steam Navigation Company, which post he held until his death on the 11th December, 1917.

He was elected a Member of the Liverpool Engineering Society on 1st April, 1914.

ANTHONY GEORGE LYSTER, the son of Mr. George Fosbery Lyster, the late Engineer-in-Chief of the Mersey Dock Estate from 1861 to 1897, was born at Holyhead in 1852, his father being at that time engineer in charge of the work at Holyhead Breakwater. He was educated at Harrow School and at Bonn, Germany, and entered the engineer's department of the Mersey Docks and Harbour Board as a pupil under his father in January, 1872, after which he passed some time at the famous Elswick works of Sir William Armstrong. When the very large and important works, under the Act of 1873, at the North and South ends of the Liverpool Dock Estate were commenced, he was engaged on them in various capacities until 1876, when, Mr. A. F. Blandy having retired on account of ill-health, Mr. A. G. Lyster became directly responsible under the engineer-in-chief for these works. They cost on the whole four million sterling, and made a very large increase to the dock accommodation on the Liverpool side of the Mersey—over 30 per cent. of that existing at the time. The works in question consisted of the enlargement of the Canada Basin, the construction of the Canada Jetties and the Langton Dock, Branch Dock and Graving Docks, the latter being each 950 feet in length, the Alexandra Dock and Branch Dock, with their fine lay out of wide sheds, all suitable for the highest class of tonnage frequenting the port then and for many years afterwards, and the Hornby Dock, the last of this series at that time in the Northern district. The Southern group of Docks brought into existence by the same scheme were the Toxteth and Harrington Docks, an enlargement of the Herculeum Dock, and the construction of an additional graving dock (No. 3) there. On the retirement of Mr. G. F. Lyster, Mr. A. G. Lyster succeeded him as Engineer-in-Chief of the Mersey Docks and Harbour Board.

In 1889, when the question of providing increased depths in the world's great channels was becoming important, and the improvement of the harbour of New York had been considered, and certain unsuccessful experiments made, it was decided, at the suggestion of Mr. Lyster, senior, to make an experiment by dredging at Liverpool, and for this purpose two of the Board's hopper barges, Nos. 5 and 7, were fitted up with pumping apparatus. A trial of these two small barges gave such encouraging results that Mr. A. G. Lyster proposed and received instruction from his Board to provide an appliance of much more powerful description, and the result was the design of the "Brancker," a sand-pump hopper dredger of unprecedented size, and having many features of an entirely novel character. This vessel was fitted with a hopper capacity of 3,000 tons, and capable of filling herself in three-quarters of an hour. Two years later followed the "G. B. Crow," of the same power—practically a sister ship. In due course the Bar of the Mersey, on which in 1889 there had been a depth at low water of spring tides of only about 11 feet, was improved to afford a depth of something like 30 feet under the same conditions, and a large amount of work had been done at shoal places in the channels above the Bar. In view of the necessity of maintaining these channels unimpaired, and possibly of affording even greater depths in the future, as well as doing other dredging work in the river, two other dredgers followed, the "Coronation," of 3,500 tons capacity, in 1903, and a monster dredger in the shape of the "Leviathan," of 10,000 tons hopper capacity, in 1908.

As was naturally to be expected from an engineer having carried out and maintained docks and harbour works on an immense scale the advice and assistance of Mr. Lyster was greatly sought after by those in all parts of the world who had problems of a somewhat similar character to face. Thus, in the matter of dredging, New York harbour, which in its earlier attempts had preceded Liverpool but without conspicuous success, eventually followed Liverpool's example, and decided to dredge by powerful suction dredgers of the "Brancker" and "G. B. Crow" type, and Mr. Lyster was consulted by a syndicate who eventually constructed large suction dredgers for that purpose on the lines of those vessels, and these were used in carrying out a large amount of dredging in the channels of the Bay of New York. Similarly on the Thames and the Hooghli, dredgers designed by Mr. Lyster, and built under his supervision, were brought to work for the amelioration of the channels.

The authorities in Port Elizabeth, Shanghai, Sekondi, on the

Gold Coast, and other ports, not to mention various English rivers, consulted him as to the design of river and harbour works, and in matters, such as dock walls and other works, his views were sought in many places.

One of his last works at Liverpool was the construction of the Gladstone Graving Dock, completed after his retirement. On retiring from the Mersey Docks and Harbour Board, Mr. Lyster became a partner in the firm of Sir John Wolfe Barry, Lyster and partners.

Mr. Lyster was a Past President of the Institution of Civil Engineers, a colonel of the Railway Staff Corps, and a member of the Commission Consultative Internationale de Travaux du Canal Maritime de Suez. Liverpool University had the benefit of his advice and assistance as Associate Professor of Dock and Harbour Engineering, and conferred on him the degree of Master of Engineering. He had been a Vice-President of the Liverpool Engineering Society, and was one of the oldest members, having belonged to the Society since 7th June, 1876.

WILLIAM SIBUN, who died in September, 1920, was born in July, 1857, and after serving an apprenticeship from 1873-1878 with Palmers Hill Engine Works, Sunderland, he became an engineer in the P. & O. Line, remaining with this Line until he was appointed Surveyor to Lloyd's Register of Shipping at Newcastle in 1887, and his subsequent service as a Surveyor to Lloyd's was at Glasgow, Cardiff and Liverpool, until he retired in 1919.

He was elected a member of the Liverpool Engineering Society on 18th February, 1914.

S. J. WHEELTON, formerly of Upholland, near Wigan, after studying mine and underground surveying entered the service of the Liverpool Corporation in 1878, at the age of 18, and after completing a progressive period of 38 years in the City Engineer's Department, he retired in 1916 owing to ill health; his death taking place four years later in 1920. Of a quiet and retiring disposition, his chief personal characteristics were integrity, courtesy, and accuracy in everything, combined with a great readiness to help those in trouble and to assist young members of the profession. A man of his word, he

was to be relied upon to the minutest detail, and nothing was too much trouble. His retirement was a loss to the public, as his intimate knowledge of the City accumulated during the long period of his service, was on very many occasions of the utmost assistance.

He was elected a Member of the Liverpool Engineering Society on 13th November, 1899.

The following Deaths have also been made known :—

Members.

H. S. BOUMPHREY.

R. B. FRASER.

Eng.-Comm. WALLIS V. BROWNE, R.N.R.

J. B. JEFFREY.

T. W. DAVIES.

J. T. RUBERY.

Members possessing information relating to the professional careers of the above, are requested to communicate with the Hon. Secretary.



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